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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1959 THANKSGIVING MEETING

AT THE

CASE INSTITUTE OF TECHNOLOGY, CLEVELAND, OHIO

November 27–28

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1959 THANKSGIVING MEETING, CASE INSTITUTE OF TECHNOLOGY, CLEVELAND, NOVEMBER 27–28, 1959

THE **Thanksgiving meeting** now makes another excursion from Chicago, only two years after the latest. It is rare for deviations from the "Chicago tradition" to come so thick and fast, and as a matter of fact we had planned the next one for 1960, for which year the Case Institute of Technology at Cleveland had invited us. Newly arisen circumstances at Chicago made it desirable to move elsewhere our convention planned for that city in 1959, and the Case Institute very graciously consented to receive us a whole year earlier than it or we had foreseen. As an entire decade has elapsed since last we met in Cleveland, the experience of visiting it will be quite new to many, and for the others new in part, since the city and the Institute have grown. The dates of our convention are **Friday and Saturday, November 27 and 28.**

The Case Institute and the Western Reserve University are close to Euclid Avenue in the eastern area of Cleveland that is dignified also by the art gallery and the symphony hall. Here also are our headquarters hotel, the Wade Park Manor (at East 107th and Chester Streets), and our "overflow" hotel, the Tudor Arms, both within walking distance of Case campus. The Pennsylvania station is at East 55th and Euclid Avenue. Of the two stations of the New York Central, East Cleveland is a little closer to the hotels than is the Union Station, but we do not know whether there are redcaps and taxis there.

The registration desk will be in Tomlinson Hall of the Case Institute of Technology. Members and guests alike must register and pay the $1.00 registration fee. Banquet tickets will be sold at the registration desk so long as any remain for sale. Announcements of post-deadline papers (if any) will be made on a blackboard near the registration desk, as well as any other announcements pertaining to this meeting. Messages may be handed in at the desk but only by people who have paid the registration fee.

Invited Papers. A Committee was appointed to recommend invited papers for the Cleveland meeting, and to its acumen we owe four groups of these: one on the knowledge attained through the famous satellite Explorer VI (Friday afternoon), one on antiprotons and hypernuclei (Saturday morning), one on resonance absorption of gamma rays (Friday morning), and the papers of Session U on Saturday afternoon. The invited papers of J. W. Hoffman, Carl Kenty, L. S. Kisslinger, J. W. McClure, and J. W. Weinberg we owe to the Cleveland Physics Society, whose participation in this meeting we welcome. Other invited papers are those of H. G. Blosser, J. G. Daunt, P. S. Freier, C. V. Heer, H. H. Nielsen, P. M. Parker, and G. K. Wertheim.

One hundred and fifty-one contributed papers are distributed among fifteen sessions. This total nearly approaches that of last year's Chicago meeting. There are papers enough on semiconductors to occupy three entire sessions. On the whole, the distribution of papers among subjects offers no surprises except one. While we normally have at least one full session on apparatus of nuclear physics, only one contribution at this meeting belongs in that field. (It is in Session P, juxtaposed with an invited paper in its field.) Is this a fluctuation or is the nuclear contingent at last contented with its tools? I incline to the former theory. As usual, it is sometimes hard to decide whether a contribution should be placed in solid-state physics or in cryogenics, and in some cases the choice was made in favor of the former because the session captioned cryogenics is the longest of all. No subject which was assigned to Saturday afternoon in the 1958 Thanksgiving meeting was so assigned this time.

The banquet of the American Physical Society will be held in the Lincoln Room of the Wade Park Manor Hotel on Friday evening at 7:00 P.M. The afterdinner speakers will be announced on the blackboard near the registration desk.

The banquet of the Thanksgiving meeting always confronts us with a special problem, owing to the ineluctable fact that it must be held on the first day of the meeting, and this affords our members little time to dally with their decisions. A guarantee must be given to the hotel at some time on Friday, and those who wait to buy their tickets until after that time will risk a disappointment unless the Society risks an excessive guarantee. At Chicago in 1958 we guessed exactly right, but this was a miracle. Some loss we are willing to incur for this, the one unifying feature of the meeting, the only one which all members can attend because there are no simultaneous sessions to splinter them into groups: but we are afraid to risk too much. We beseech the members to fill out and mail the form which they will find at the bottom of page 437; those who pay by checks mailed with the form, and received not later than November 25, will find their tickets waiting for them at the desk. Those who send in the form without a check will find their tickets at the desk if they apply before 2 P.M. *Those who do not fill out the form are asked to make the buying of tickets their first business on Friday morning.*

A cocktail-party will be offered to the members of our Society by the Clevite Corporation (Electronics Research Division), the General Electric Company (Lamp Division), and the National Carbon Research Laboratories, to all of whom our anticipatory gratitude is hereby expressed. This pleasant experience will be in the Lounge of the Wade Park Manor Hotel, beginning at 6:00 P.M. on Friday. Please regard it as a preparation and not as a substitute for the banquet.

After the banquet, members of the American Physical Society are invited to be guests of the Cleveland Physics Society and the Carling Brewing Company at the Social Hall of the Carling Brewing Company, 9400 Quincy Avenue, Cleveland. Beer will be available through the courtesy of Carlings. The beer will be unlimited but the capacity of the hall will not be, and so, admission will be by ticket given out at the registration desk. There is ample parking space directly across from the entrance to Carlings.

The Council of the American Physical Society will meet in the Conference Room of the Physics Building at 1:30 P.M. on Saturday unless the Councillors are notified otherwise by special message.

Post-deadline 10-min papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, November 20. The titles of such papers as are accepted will be written on a blackboard near the registration desk, and opportunity for presentation of the papers will be given at the end of Session S or possibly elsewhere in the programme. The abstracts will not be published.

Prospective meetings and deadlines of the Society will be found listed on page 435 of this Bulletin, and preliminary announcements of the 1960 Annual Meeting and the 1960 Southwestern meeting on page 432.

Make a habit of reading the instructions for the preparation of abstracts, which appear in all issues of the Bulletin and in this one are to be found on page 436. From time to time they become more stringent, for their purpose is to reduce the waste of labor and loss of time spent in editing (i.e., getting ready for the press) abstracts that are badly prepared. Indeed some of the advice that has been repeatedly given for years is not universally heeded; we are still getting occasional abstracts that are single-spaced, offered only as carbon copies, or longer than is allowed; we are on the verge of rejecting all abstracts that do not conform to the instructions. A triad of new instructions are added this year; they are printed in italics.

Errata pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, November 30, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Write out the corrections in the form "Instead of . . . read. . . ." Do not add anything. The privilege of inserting errata is not accorded to enable people to publish additional data or to restore material cut out because the abstract was too long.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1959 CLEVELAND MEETING

(Personal names are those of invited speakers, except Tomlinson, Bingham, and Strosacker which are those of halls.)

Friday Morning

10:45 A. Meyer-Schutzmeister, Nagle. Bingham 103.

10:15 B. Pions, muons, and cosmic rays. Strosacker.

10:15 C. Reactions of transmutation I. Physics 301.

10:15 D. Theoretical physics. Physics 316.

10:15 E. Luminescence; semiconductors I (compounds). Tomlinson.

Friday Afternoon

2:15 G. Semiconductors II: silicon and germanium; Wertheim. Tomlinson.

2:00 H. Metals; cryogenics. Bingham 103.

2:15 J. Reactions of transmutation II; fission; neutron physics. Physics 301.

2:15 K. Nielsen, P. M. Parker; paramagnetic resonance. Electrical Engineering 322.

2:00 L. First fruits of the satellite Explorer VI: Meyer, Winckler, Helliwell, Sonett, Rosen, Eugene Parker. Strosacker.

Friday Evening

6:00 Cocktail party. Lounge, Wade Park Manor Hotel.

7:00 Banquet of the American Physical Society; speakers to be announced. Lincoln Room, Wade Park Manor Hotel.

Late Party at Carling Brewery (see Preamble).

Saturday Morning

9:30 N. Antiprotons and hypernuclei: Goldhaber, Levi Setti, Dalitz, Fry, Block. Strosacker.

9:30 P. Blosser; nuclear apparatus; nuclear magnetic resonance and hyperfine structure. Bingham 103.

9:30 Q. General physics. Electrical Engineering 322.

9:30 R. McClure; semiconductors III. Tomlinson.

10:00 S. Daunt, Heer, Freier. Post-deadline papers, if any. Physics 301.

Saturday Afternoon

1:30 U. Crane, Penman, Connor. Strosacker.

1:30 V. Hoffman; magnetism and ferroelectricity. Bingham 103.

1:30 W. Kenty, Kisslinger, Weinberg. Physics 301.

1:30 X. Radioactive nuclei. Physics 316.

1:30 Y. Solid-state physics. Tomlinson.

PROGRAMME

FRIDAY MORNING AT 10:45

Bingham 103

(A. H. BENADE presiding)

Invited Papers

A1. Nuclear Resonance Absorption of Gamma Rays at Low Temperatures. LUISE MEYER-SCHÜTZMEISTER, *Argonne National Laboratory.* (30 min.)

A2. Resonance Absorption of Gamma Rays in Crystals. D. E. NAGLE, *Los Alamos Scientific Laboratory.* (30 min.)

FRIDAY MORNING AT 10:15

Strosacker Auditorium

(J. R. WINCKLER presiding)

Pions, Muons, and Cosmic Rays

B1. Charge Exchange Scattering of Negative Pions by Protons at 61, 95, and 150 Mev.* W. J. KERNAN, C. M. YORK, AND E. L. GARWIN, *University of Chicago.*—The charge exchange scattering of negative pions by protons on hydrogen has been measured at 61, 95, and 150 Mev. At four or more angles for each incident pion energy, the energy spectra of gamma rays from the neutral pions were measured with a lead glass Čerenkov counter. These spectra were analyzed to determine the differential cross section for charge exchange scattering that would produce them. The total cross sections obtained by integration are 7.7 ± 0.3 mb at 61 Mev, 13.2 ± 0.5 mb at 95 Mev, and 42.6 ± 1.4 mb at 150 Mev. The differential cross sections will be presented.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B2. Charge-Exchange Scattering of Negative Pions by Hydrogen at 260, 317, and 371 Mev.* JOHN C. CARIS, WALTON A. PERKINS III, ROBERT W. KENNEY, EDWARD A. KNAPP, AND VICTOR PEREZ-MENDEZ, *Lawrence Radiation Laboratory, Berkeley.*—The differential cross section for charge-exchange scattering of negative pions by hydrogen has been observed at nine laboratory angles for incident pion energies of 260 ± 7 and 317 ± 8 Mev, and at ten angles for 371 ± 9 Mev. The reaction was observed by detecting one gamma ray from the π^0 decay with a scintillation-counter telescope. A least-squares analysis was carried out to fit the observations to the function

$$\frac{d\sigma}{d\omega}=\sum_{l=0}^{4} a_l P_l(\cos\theta)$$

in the c.m. system. Preliminary results in units of mb are: at 260 ± 7 Mev: $a_0=1.822\pm0.049$, $a_1=1.550\pm0.093$, $a_2 1.968\pm0.145$, $a_3=-0.027\pm0.107$, $a_4=0.031\pm0.352$; at 317 ± 8 Mev: $a_0=1.279\pm0.023$, $a_1=1.627\pm0.042$, $a_2=1.328\pm0.067$, $a_3=0.028\pm0.053$, $a_4=-0.328\pm0.152$; at 371 ± 9 Mev: $a_0=1.042\pm0.045$, $a_1=1.414\pm0.069$, $a_2=1.024\pm0.120$, $a_3=-0.036\pm0.086$, $a_4=0.137\pm0.225$. These results indicate that d-wave scattering in the charge-exchange reaction is not not established in this energy range.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

B3. Model of the High-Energy Peaks in Pion-Nucleon Collision Cross Sections.* D. B. LICHTENBERG, *Michigan State University,* AND M. H. ROSS AND JOHN HIGGINS, *Indiana University.*—A phenomenological model is considered as a possible explanation for the peaks in the pion-nucleon total cross sections at 650-, 900-, and 1300-Mev energy. According to the model, the peaks are basically caused by resonances in the channel in which an additional pion is produced. The proposed mechanism is that one or both of the final state pions may interact with the nucleon in the well-known 200-Mev resonant state of isotopic spin 3/2, angular momentum 3/2 ((3,3) state). The fraction of the time each pion is in the (3,3) state with respect to the nucleon depends on the total isotopic spin and total angular momentum configuration of the system. We make the following simplifying assumptions about the final state: (1) the motion of the nucleon can be neglected; (2) the first pion is in the (3,3) state with respect to the nucleon (afterward the wave function is symmetrized with respect to the two pions); and (3) the orbital angular momentum of the second pion has the lowest possible value consistent with the angular momentum and parity of the system. It is found that unique predictions can be made for the branching ratios into the various two-pion charge states unless the parity of the system is even and the total angular momentum is $\leq 5/2$.

* Work supported in part by the National Science Foundation.

B4. Internal Pairs Following π^- Capture in Hydrogen.* M. DERRICK, J. FETKOVICH, T. FIELDS, AND J. DEAHL, *Carnegie Institute of Technology.*—A six-inch hydrogen bubble chamber in a magnetic field of 10 kilogauss has been used to study internal electron pairs following π^- capture at rest. 2014 examples have been found and analyzed. By a geometrical cut-off on the angle bisector of the electron directions, 1313 events suitable for momentum measurement have been selected. Two peaks in the energy spectrum corresponding to the two reactions (1) $\pi^-+p\rightarrow n+e^++e^-$, (2) $\pi^-+p\rightarrow(n+\pi^0)\rightarrow n+e^++e^-+\gamma$, were seen. Assuming theoretical values[1,2] for the gamma-ray internal conversion coefficients of 0.00717 for reaction (1) and 0.0118 for reaction

(2), the Panofsky ratio was measured to be 1.47 ± 0.10. Distributions of the pairs in opening angles, energy partition, and virtual photon mass will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] N. M. Kroll and W. Wada, Phys. Rev. **98**, 1355 (1955).
[2] R. M. Rockmore and J. G. Taylor, Phys. Rev. **112**, 992 (1959).

B5. Slowing-Down Time of π^- in Liquid Hydrogen.* T. FIELDS, G. B. YODH, M. DERRICK, AND J. FETKOVICH, *Carnegie Institute of Technology.*—In order to determine (or set an upper limit to) the cascade time of π^- in hydrogen, we have observed $\pi\rightarrow\mu$ decays of π^- coming to rest in a hydrogen bubble chamber. In 30 000 π^- stops, 20 $\pi\rightarrow\mu$ decays with the muon laboratory momentum making an angle of at least 90° with respect to the pion laboratory momentum were found. By using 120° as the cutoff angle, we determined from the muon ranges that one $\pi\rightarrow\mu$ decay for which $\beta_\pi<0.05$ was seen. These data are consistent with ordinary stopping power theory[1]; they further imply that the time elapsed between $\beta_\pi=0.05$ and capture by a proton is $\approx6\times10^{-12}$ sec, to within about a factor of 3. Further data will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] A. S. Wightman, Phys. Rev. **77**, 521 (1950).

B6. Gamma-Ray Energy Spectrum from $\mu^+\rightarrow e^+ +\nu+\bar{\nu}+\gamma$.* C. O. KIM, W. J. KERNAN, AND C. M. YORK, *University of Chicago.*—The energy spectrum of the gamma rays emitted by the inner bremsstrahlung from the $\mu-e$ decay process has been measured with the aid of a large sodium iodide crystal. Pulses in this crystal were pulse-height analyzed only if they were time coincident with an electron detected by a scintillation counter telescope. The solid angle of acceptance of these counters is such that all angles from 0° to 26° between the electrons and gamma are detected. Positive pions were stopped in a carbon or aluminum target of equal stopping power. By using targets of two different materials the contribution of the externally produced bremsstrahlung could be taken into account. The results of a comparison of the experimental spectrum with the theory will be presented.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B7. *K*-Shell Ionization by Relativistic Mesons.* L. VOYVODIC, I. FILOSOFO, AND T. G. STINCHCOMB,† *Armour Research Foundation.*—In studying penetration mechanisms of very fast particles, we have carried out initial experiments on the ionization cross sections for mu mesons with average kinetic energies ~20 rest mass units interacting with *K*-shell electrons in tin and in lead. The experimental arrangement utilized a 5-in. diameter$\times\frac{1}{4}$ in. thick NaI(Tl) scintillator with 256 channel pulse-height analyzer to view characteristic *K* x-rays in coincidence with sea-level cosmic-ray mu mesons traversing the target foils and a three tray counter telescope. Comparison is made with cross sections deduced from the Bethe-Burhop nonrelativistic theory for hydrogenic atoms. Preliminary data indicate that the ratio of observed to calculated *K* ionizations is ~2.5 for tin and ~5.0 for lead. The results will also be discussed in terms of the character of energy transfers in distant collisions and the effect of *K* electron velocities in heavy atoms.

* Supported by Armour Research Foundation Basic Research Fund.
† Now at Heidelberg College.

B8. Polarization of Cosmic-Ray Muons at Sea Level.* C. SCOTT JOHNSON,† *Washington University.*—Cosmic-ray muons at sea level are known to be partially longitudinally polarized. The object of this experiment was to measure the muon polarization by stopping the muons in a copper absorber and observing the up:down asymmetry in the decay electrons. Measurements were also made with iron and sulfur as control absorbers to test the asymmetry of the apparatus. Since this experiment is performed in zero magnetic field it has been possible to verify that unmagnetized iron depolarizes muons by precessing their magnetic moments in the strong randomly oriented magnetic fields of the domains. The up:down ratio of decay electrons was 1.14 ± 0.02 for copper, 0.98 ± 0.02 for iron, and 1.02 ± 0.03 for sulfur. On the basis of the two-component neutrino theory the muon polarization is found to be $>21\pm3\%$, where the inequality is due to depolarization effects. There is evidence that, in the absence of external magnetic fields, copper depolarizes the stopped muons, as indicated by a decrease in the up:down ratio with time.

* Supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and the Air Office of Scientific Research.
† Now at the University of Chicago.

B9. Composition of the Radiation in the Lower Van Allen Belt. R. G. JOHNSON, *Lockheed Missiles and Space Research Laboratory,* AND F. E. HOLLY, *Air Force Special Weapons Center.*—A measurement has been made on the composition of the radiation trapped in the earth's magnetic field in the altitude region from 650 to 990 km. An instrument package containing eight Geiger counters, collimated and shielded in various ways, was carried aloft and released by an Atlas missile. The energy spectrum of the radiation was determined from six counters shielded with five different absorber thicknesses in the range from 1.7 to 2000 mg/cm². The spectrum has a very large component for lower energies with less than 1% of the radiation penetrating 150 mg/cm² of aluminum. By magnetic selection on one of a pair of otherwise identical counters, an upper limit of 0.03 ± 0.05 is found for the proton contribution to the radiation which penetrates 30 mg/cm².

B10. Radiation Measurements to 658 300 Kilometers with Pioneer IV. JAMES A. VAN ALLEN, *State University of Iowa.*—Comparison of new observations (3 March 1959) on the geomagnetically trapped radiation with those of 6, 7 December 1958 and 2 January 1959 shows a great augmentation of the outer zone due apparently to an *M*-region solar event in latter February. The inner zone was little affected. In combination with previous U. S. and U. S. S. R. satellite and space-probe observations and low-altitude rocket work of Holly and Johnson and of Freden and White, we find following omni-directional intensities (3 March 1959) in $(\text{cm}^2\ \text{sec})^{-1}$. In heart of outer zone electrons $E>20$ kev, 10^{11}; $E>200$ kev, $<10^8$; protons $E>60$ Mev; $<10^2$. In heart of inner zone electrons $E>20$ kev, 10^9; $E>600$ kev, 10^7; protons $E>40$ Mev, 2×10^4. The interplanetary cosmic-ray intensity is $\leq1.8\pm0.3$.

B11. Satellite Observations of the Effect of the Great Magnetic Storm of September 4-5, 1958, on Charged Particles Trapped in the Earth's Magnetic Field. C. E. MCILWAIN AND P. ROTHWELL, *State University of Iowa.*—A detailed study has been made for the period September 1–12, 1958, of the variation of the intensity of particles trapped in the earth's magnetic field at altitudes between about 1000 km to 2000 km above North America and Australia. Intensities were measured with two Geiger counters carried in the Explorer IV satellite 1958 epsilon (one shielded with 1.6 g/cm² of lead, the other unshielded except for the satellite hull). (1) On September 4–5, during the magnetic storm, both counters showed a sharp drop in counting rate in the outer Van Allen radiation zone and in the artificial "Argus" electron shells. (2) After the storm, the unshielded Geiger counter rate in the outer zone returned to about prestorm level, but the shielded counter rate increased to about ten times the prestorm level. (3) No significant change in intensity of particles in the inner zone was detected during this period. The significance of these results will be discussed.

B12. Semidiurnal Variation and the Barometric Coefficient of the Nucleonic Component. J. KATZMAN AND D. VENKATESAN, *National Research Council, Canada.*—A study of the time variation of cosmic-ray intensity and a proper interpretation is possible only after the removal of all meteorological effects. The nucleonic component is sensitive to barometric pressure changes only and the barometric coefficient at sea level and moderate mountain altitudes is expected to be the same at all stations irrespective of latitude. It is well known that the second harmonic component of barometric pressure is nearly constant in local time for all stations within the geographical belt 60°N to 60°S and in Greenwich time for the higher latitudes. Hence, it is possible to obtain a universal barometric coefficient, if a large number of stations are combined for the analysis. The Ottawa data for the period January 1956–January 1959 exhibited a high correlation between the second harmonic components of barometric pressure and the nucleonic intensity, and the coefficient obtained by this method was −0.76% per mb. A coefficient of −0.78% per mb was obtained by means of the second harmonic after combining the data from Churchill, Ottawa, Sulphur Mountain, Chicago, Uppsala, Kampala, Kodaikanal, Lae, and Mt. Wellington, and a value of −0.76% per mb for the combined data of Mawson and Resolute for the common period November 1957 to October 1958. This method of obtaining a barometric coefficient was compared with the method suggested by Forbush.

FRIDAY MORNING AT 10:15

Physics 301

(BEROL ROBINSON presiding)

Reactions of Transmutation, I

C1. Angular Distributions of the Polarization of Neutrons from the $Li^7(p,n)Be^7$ Reaction.* S. M. AUSTIN, S. E. DARDEN, A. OKAZAKI, AND Z. WILHELMI, *University of Wisconsin.*—The angular distribution of the polarization of neutrons from the $Li^7(p,n)Be^7$ reaction has been measured using methods previously described.[1] At proton energies of 2.2, 2.6, and 3.0 Mev the angular ranges covered were 30° to 85°, 30° to 115°, and 30° to 70°, respectively. At 2.6 Mev the magnitude of the polarization increased to a maximum at approximately 60°, then decreased rapidly and was nearly zero at 105° and 115°. At 2.2 and 3.0 Mev the polarization increased for angles up to about 50°, then remained approximately constant to 85° and 70°, respectively. At 50° additional measurements were made between 2.4 and 2.8 Mev. The magnitude of the 50° polarization decreased between 2.2 and 2.4 Mev, increased between 2.4 and 2.6 Mev, then leveled off to a nearly constant value for higher proton energies.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

[1] Striebel, Darden, and Haeberli, Nuclear Phys. 6, 188 (1958).

C2. Excitation Function and Angular Distribution for the Reaction $Li^7(p,\gamma)Be^8$. N. W. REAY AND N. M. HINTZ, *University of Minnesota.*—The excitation function and angular distribution for the reaction $Li^7(p,\gamma)Be^8$ was determined using the 10-Mev beam of the University of Minnesota linear accelerator. The beam energy was varied by means of absorbers placed in the beam path. σ (90°) was measured for center-of-mass proton energies at target center of 4.3, 5.3, 6.2, 7.2, and 8.0 Mev. The γ-ray angular distribution was measured at E_p c.m. = 8.0 Mev. Points were taken at 15° intervals from 45° to 135°. The data were measured absolutely to within 17%, and relatively to within 7%. The angular distribution can be fitted at every point within the relative error by the formula $\sigma(\theta) = (0.450 + 0.466 \sin^2\theta + 0.280 \sin^2\theta \cos\theta) \times (10^{-29}$ cm^2/sterad). The excitation function varied by less than a factor of two over the energy range studied, but showed a distinct rise at the lowest energies, a minimum near E_p c.m. = 6.2 Mev, and a slow rise at higher energies. The low energy rise could be attributed to a process inverse to the giant resonance, as suggested by Wilkinson.[1] The high energy rise is shown to be consistent with a predominately D-wave direct-interaction mechanism.

[1] D. H. Wilkinson, Phil. Mag. 45, 259 (1954).

C3. $B^{10}(t,p)B^{12}$, $B^{10}(t,d)B^{11}$, and $B^{10}(t,\alpha)Be^9$ Reactions. H. D. HOLMGREN, R. L. JOHNSTON, AND E. A. WOLICKI, *U. S. Naval Research Laboratory.*—The investigation of the reaction mechanisms for the interactions of mass-3 particles with light nuclei has been extended to include triton interactions. This paper reports the work of one in a series of such investigations in which the angular distributions and yield curves of the charged particles emitted from the interaction of tritons with B^{10} have been measured. The yield curves at 90° and 163° corresponding to the 3 highest-energy proton groups and the ground-state deuteron group appear to increase monotonically with the bombarding energy in the region extending from 0.80 to 2.00 Mev. The yield curve of the ground-state α-particle group exhibits a weak maximum at about 1.40 Mev. The angular distributions of the ground-state and first-excited-state proton groups show a small anisotropy, with rather weak forward maxima at low bombarding energies. At 1.95 Mev these angular distributions have weak maxima at larger angles. The angular distribution of the ground-state deuteron group appears to have a minimum at about 10° and a maximum at 80° for a bombarding energy of 0.90 Mev. The minimum shifts to about 40° at 1.95 Mev; but the maximum at 80° appears to remain fixed. The angular distribution of the ground-state α-particle group has a minimum at about 90° for bombarding energies of 0.90 and 1.95 Mev.

C4. Differential Cross Sections for the $O^{16}(t,p)O^{18}$ and $O^{16}(t,\alpha)N^{15}$ Reactions. R. L. JOHNSTON, H. D. HOLMGREN, AND G. D. GUTSCHE, *U. S. Naval Research Laboratory.*—The tritium beam of the Nucleonics Division 2-Mev Van de Graaff accelerator was used to bombard thin NiO targets for the investigation of the $O^{16}(t,p)O^{18}$ and $O^{16}(t,\alpha)N^{15}$ reactions. The differential cross sections at 90° and 163° for protons leaving the residual nuclei in the ground state and first-excited state were measured as functions of the bombarding energy in the range extending from 1.0 to 2.0 Mev. The 90°-differential cross sections increase rapidly with bombarding energy to a value of 2 mb/steradian and 6 mb/steradian at 1.975 Mev

for the ground-state and first-excited groups, respectively. The differential cross sections for the ground-state α-particle group at 90° and 163° were also measured for the same range of bombarding energies. The 90° differential cross sections were found to pass through a broad maximum of about 6 mb/steradian at 1.775 Mev. Angular distributions were measured at bombarding energies of 1.150, 1.300, 1.500, 1.775, and 1.950 Mev. The angular distributions of the ground-state proton group exhibit a strong forward maximum which increases with bombarding energy and a minimum which shifts from 40° at 1.150 Mev to about 70° at 1.950 Mev. At 1.950 Mev the ratio of the 0° yield to that at 70° is about 50 to 1. The yield of the first-excited-state proton group increases with increasing angle to all energies.

C5. $(p,p'\gamma)$ Azimuthal Correlation in C^{12} at 40 Mev.* HARRY S. ADAMS, *University of Minnesota.*—The azimuthal angular correlation of the de-exciting gamma ray and the inelastic proton scattered from the 4.43-Mev level in C^{12} has been measured for an incident proton energy of 40 Mev. Data have been obtained for four different combinations of proton and gamma-ray polar angles. The results are in agreement with the Levinson-Bannerjee[1] model for the direct interaction and favor the distorted wave description of this process. The data are also consistent with the *j-j* coupling scheme for the target nucleus wave functions.

* Supported in part by the U. S. Atomic Energy Commission.
[1] C. A. Levinson and M. K. Bannerjee, Ann. Phys. (N. Y.) **2**, 499 (1957).

C6. Angular Distributions from the $C^{12}(d,p)C^{13}$ Reaction at Deuteron Energies of 14.7, 12.4, and 10.2 Mev.* E. W. HAMBURGER, *University of Pittsburgh.*—A polyethylene target was bombarded with deuterons from the University of Pittsburgh Cyclotron. Different incident energies were obtained by inserting Ta degrading foils in front of the target; collimating slits minimized the effects of multiple scattering. The reaction products were magnetically analyzed and detected in nuclear emulsions. Exposures were made at 13 scattering angles from 10° to 85°, at deuteron energies of 14.7 (no degradation), 12.4, and 10.2 Mev. The energy spread of the incident beam had half widths of ~70, 200 and 300 kev, respectively, at these energies. The differential cross section for the formation of the C^{13} g.s. increases with decreasing energy. The stripping peak in the angular distribution does not shift toward larger angles at lower energies, as predicted by simple theory. Consequently the radius parameter in the Butler formula must be varied to obtain a reasonable fit to the data: $r_0 \cong 4.0$ f at 14.7 Mev and $r_0 \cong 5.1$ f at 10.2 Mev. The reduced width θ^2 is found to be ~0.034, 0.038 and 0.040 at 14.7, 12.4, and 10.2 Mev, respectively.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C7. Nuclear Levels of Na^{24} in the kev Region.* CARL T. HIBDON, *Argonne National Laboratory.*—A complicated level structure has been observed for Na^{24} in a study of the nuclear levels of sodium up to 500 kev by the $Na^{23}(n,n)$ process.[1] The data show a number of relatively large peaks, and many smaller ones among the 127 levels observed, the widths ranging from 0.2 to 6 kev. Approximately 50 small peaks were observed between 60 and 200 kev. Above 200 kev, each of the previously known peaks was resolved into two or more peaks, and between these large peaks many narrower peaks were observed. Numerous levels, among which are the peaks at 2.95, 54.1, 55, 202.7, 205.2, 242, and 246.3 kev, have been studied intensively. Tentative analyses show only a small number of *s*-wave levels. A plot of the number of levels having energies E_n as $\leqslant$ a function of the neutron energy E_n shows an essentially linear distribution of the levels. No downward curvature occurs in the plot to indicate a general missing of levels in the high-energy region. Deviations from linearity may be attributed in part to the missing of very narrow levels and in part to a random occurrence of levels.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. T. Hibdon, Phys. Rev. **108**, 414 (1957); **114**, 179 (1959).

C8. Angular Correlation Study of the $Mg^{24}(d,p\gamma)Mg^{25}$ Reaction.* J. P. MARTIN AND K. S. QUISENBERRY, *University of Pittsburgh.*—Angular correlations between protons from the $Mg^{24}(d,p)Mg^{25}$ reaction leading to the 3.40-Mev excited state and the resulting de-excitation gamma rays were studied using a natural magnesium target bombarded by 15-Mev deuterons. Correlation measurements were made in two mutually perpendicular planes with the proton detector both near the stripping maximum ($\theta_{lab}=15°$) and off the maximum ($\theta_{lab}=45°$). The coordinate system used to describe the correlations is defined with the z axis in the $K_d \times K_p$ direction and the x axis in the recoil nucleus direction. Correlation functions found by least squares fitting to the experimental data are, for the 15° proton angle, $W(\pi/2,\phi)=1+(0.385 \pm 0.023)\cos^2(\phi-\phi_0)$ with $\phi_0=-27.7°\pm 2.9°$ and $W(\theta,\phi_d)=1+(0.145\pm 0.029)\cos^2\theta$ where ϕ_d is the beam direction. The functions found for the 45° proton angle are $W(\pi/2,\phi)=1+(0.366\pm 0.033)\cos^2(\phi-\phi_0)$ with $\phi_0=-6.8°\pm 3.5°$ and $W(\theta,\phi_d)=1+(0.279\pm 0.038)\cos^2\theta$. These observed correlations are in good agreement with the predictions of the distorted wave theory.[1]

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Huby, Refai, and Satchler, Nuclear Phys. **9**, 94 (1958/59).

C9. Angular Distributions of Tritons from the $Mg^{26}(d,t)Mg^{25}$ Reaction.* A. G. BLAIR AND E. W. HAMBURGER, *University of Pittsburgh.*—Deuterons of 14.8-Mev incident energy were used to bombard an enriched Mg^{26} metallic target. The reaction products were magnetically analyzed, then detected with a scintillation crystal. The angular distributions of the tritons from the Mg^{25} G. S., 0.58-, 0.98-, 1.61-, 1.96-, 2.56-, 2.80-, and 3.40-Mev levels were obtained by observing the triton groups at several scattering angles between 6° and 70°. The distributions from the 1.62- and the 3.40-Mev levels are approximately isotropic. Butler curves for $l=0$ fit the distributions for the 0.58- and 2.56-Mev levels, while the G. S., 0.98-, 1.96-, and 2.80-Mev levels are fitted by $l=2$ curves; the reduced widths θ^2 are 0.0025, 0.0007, and 0.031, 0.0004, 0.0018, and 0.0009, respectively. The l values are in agreement with the known spins of the levels. On the basis of the rotational model the two last neutrons in the Mg^{26} G. S. should have $K=5/2$ (Nilsson's orbit #5). The present results suggest, however, a ~15% admixture of $K=1/2$ bands (orbits #9 and #11).

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C10. Lifetimes of Excited States of V^{51} and As^{75}.* E. N. SHIPLEY,† F. J. LYNCH, AND R. E. HOLLAND, *Argonne National Laboratory.*—The lifetimes of Coulomb-excited states in As^{75} and V^{51} have been measured by a pulsed-beam technique.[1] The states to be measured were excited by a 3.5-Mev pulsed alpha-particle beam from the Argonne electrostatic accelerator; the de-excitation gamma rays were detected in a NaI(Tl) scintillator. The measured mean lifetimes are 0.28 ± 0.05 mμ sec for the 320-kev level of V^{51}; 1.30 ± 0.15 mμ sec for the 200-kev level of As^{75}; and 0.4 ± 0.2 mμ sec for the 280-kev

level of As^{75}. The measurement of the 280-kev level in As^{75} was complicated by the possible excitation of the 265-kev level[2] in As^{75} since radiations from the two levels could not have been resolved. The lifetime of the 325-kev level in V^{51} has been previously measured by Sunyar[3] (0.28 ± 0.03 mμ sec) by a delayed-coincidence technique, and by Schopper[4] (0.15 ± 0.03 mμ sec) who observed the resonance fluorescence.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Physics Department, Northwestern University.
[1] Holland, Lynch, and Hanna, Phys. Rev. **112**, 903 (1958).
[2] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).
[3] A. W. Sunyar, *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958* (United Nations, Geneva, 1959), Vol. 14, p. 347.
[4] Herwig Schopper, Z. Physik **144**, 476 (1956).

C11. (n,p) Reaction for Cobalt at 14 Mev.* J. R. HEARST, SE HEE AHN,† E. N. STRAIT, AND J. H. ROBERTS, *Northwestern University.*—In the same manner as the previous work with zirconium[1] the energy and angular distributions of the protons from the interaction of 14.1-Mev neutrons with Co^{59} have been obtained. A forward peak in the high-energy proton angular distribution has again been found. The cross section for the reaction is considerably higher than that for zirconium. The significance of these results in terms of the compound nucleus and direct interaction models will be discussed, with a comparison of square and diffuse nuclear potentials for the compound nucleus model. The results will also be compared with results of similar experiments[2-4] on Cu, Fe, and Ni.

* Work supported by the U. S. Atomic Energy Commission through Argonne National Laboratory Subcontract.
† Present address: Yonsei University, Seoul, Korea.
[1] Ahn, Hearst, Roberts, and Strait, Bull. Am. Phys. Soc. Ser. II, **4**, 359 (1959).
[2] D. L. Allan, Nuclear Phys. **6**, 464 (1958).
[3] P. V. March and W. T. Morton, Phil. Mag. **3**, 143 (1958).
[4] Colli, Facchini, Marcazzan, and Sona, *Proceedings of International Conference on the Neutron Interactions with the Nucleus, Columbia University, 1957*, p. 210.

C12. Cross Sections for the $Zn^{64}(n,2n)Zn^{63}$ and $Ag^{107}(n,2n)Ag^{106m}$ Reactions. D. R. KOEHLER AND W. L. ALFORD, *Redstone Arsenal.*—The relative cross sections for the $Zn^{64}(n,2n)Zn^{63}$ and $Ag^{107}(n,2n)Ag^{106m}$ reactions have been measured for neutrons ranging in energy from 12.3 to 18.2 Mev. A tritium-zirconium target bombarded with deuterons from the Research Laboratory 2-Mev Van de Graaff accelerator served as the source of neutrons. Yields of 38-min Zn^{63} and the 24-min isomer of Ag^{106} were determined by measuring the respective beta activities. Cross section curves, fitted to absolute values at 14 Mev,[1] are presented and in the case of zinc are compared with previous results.[2]

[1] L. A. Rayburn, Bull. Am. Phys. Soc. Ser. II, **3**, 337 (1958); S. G. Forbes, Phys. Rev. **88**, 1309 (1952); E. P. Paul and R. L. Clarke, Can. J. Phys. **31**, 267 (1953).
[2] A. V. Cohen and P. H. White, Nuclear Phys. **1**, 73 (1956).

FRIDAY MORNING AT 10:15

Physics 316

(L. S. KISSLINGER presiding)

Theoretical Physics

D1. Is the Red Shift a Doppler Effect? M. FORRO-BARNOTHY, *University of Illinois.*—Metaphysical creation acts inherent in present-day cosmologies were forced upon us to reconciliate the red-shift phenomenon with the finite density of matter and to escape difficulties connected with static cosmological solutions. It will be shown that the explanation of the red shift as a Doppler effect does not have adequate experimental evidence, and that the equilibrium of a static Einstein universe is not labile. To cope with problems like red shift, cosmological term, Olber's paradoxon, and entropy death, the assumption is made that the metric of signal carriers changes relative to the metric of elementary particles. In a steady-state universe this change has to be an exponential function of time, with positive, imaginary, or zero exponent. The case of positive exponent is realized in the electromagnetic radiation, leading to a nonlinear red shift, excess reddening, cosmic radiation, and evolution of stars. The case of imaginary exponent is realized in the gravitational field, leading to the cosmological term. The case of zero exponent is realized in the neutrino radiation emitted in nuclear processes occurring in stars. For signal carriers arriving from vast distances, the case of negative exponent is ruled out, because it would necessitate metaphysical creation acts to maintain conservation of energy; but it is realized in the short-range nuclear fields.

D2. Electromagnetic Structure of Nucleons. J. M. BARNOTHY, *Evanston, Illinois.*—High-energy electron scattering experiments have been interpreted as evidence for the finite size of nucleons. The proposed model of elementary particles sets out from the assumption that elementary particles are closed universes like our own, with smaller length and mass units. Due to their curved space we "see" them as surfaces of constant curvature, the interaction itself being determined through the assumption that every cosmological quantity of the "smaller" world is observable as a quantity of the same dimensions, but multiplied by a factor $(-1)^{n/2}$, where n is the number of dimensions of the quantity. E.g., the cosmological constant λ in the gravitational potential of the "smaller" universe reverses its sign, leading to a short-range gravitational attraction between nucleons, with a gravitational constant $G=2.7\times10^{20}$ cgs. The model provides for the electromagnetic structure of the proton a form factor $F_e=F_m=(1+4q^2\lambda^2)^{-1}$; for that of the neutron $F_e=6\times10^{-4}q^2$ and $F_m=(1+4q^2\lambda^2)^{-1}-1.5\times10^{-3}q^2$; for that of the alpha particle $F_e(1-4q^2\lambda^2)\times(1+4q^2\lambda^2)^{-1}+0.013q^3$, where λ is the Compton wavelength of the proton and q the energy momentum transfer. The main term of the form factors is due to a deviation from the Coulomb law, the finite size of the nucleons providing merely correction terms.

D3. Thermodynamic Quantities and Pair Distribution Function. S. FUJITA, *Northwestern University.*—Assuming a system of identical particles interacting through pair forces, the internal energy is obtained as in integral form of the pair distribution function:

$$E(\beta)=E_0(\beta)+\tfrac{1}{2}V\int_0^{g}dg'\int d^3r v(r)\frac{\partial}{\partial\beta}\beta n^{(2)}(r;\beta,g'),$$

where $E_0(\beta)$ is the kinetic energy of the free-particle system with the same statistics as that of the system in consideration and $n^{(2)}(r;\beta,g')$ is to be calculated with coupling strength $=g'$. $\beta=(kT)^{-1}$, V volume, and v the pair interaction potential. The pressure of the system is also written in terms of the pair

distribution function. While the pair distribution function can be directly expanded in terms of collective interactions, the partition function cannot. Therefore the evaluation of the thermodynamic quantities via the pair distribution function is more advantageous than the usual calculation via the partition function when the collective motion description is important. This is illustrated by taking the electron gas and the hard-sphere Bose gas as examples.

* This work was supported by the Office of Naval Research.

D4. Electromagnetic Vortex Theory in Free Space. W. R. MELLEN, *Lowell Technological Institute.*—To explain the internal structure of the electron an electromagnetic vortex theory has been developed based on the flow of electromagnetic energy in free space. The theory permits charged and uncharged vortices and requires vortex rings of both types to have a magnetic moment, in qualitative agreement with properties of elementary particles. The basic assumption of the theory is that electromagnetic flow as in a part of a plane electromagnetic wave is a fundamental entity. Two such flows while interacting keep their separate identities. A flow moves with the velocity of light, and a divergence of the electric field of one flow (or the flow's charge) moves with this velocity. The mass density associated with each flow is equal to the relativistic mass density associated with it in free space. The electric and magnetic forces are equal to the classical forces subject to the above modifications and produce a normal acceleration of the mass of the electromagnetic flow. The theory has been applied to flows in cylindrical coordinates and results extrapolated for vortex rings. With no apparent restriction on size, electromagnetic vortices of laboratory or astronomical dimensions are conceivable.

D5. Unification of Relativity and Quantum Mechanics. B. KIVEL, *Avco Everett Research Laboratory.*—Quantum mechanics and special relativity should be unified. The Einstein postulates of special relativity state that in all inertial systems both the physical laws are the same and the velocity of light has the same value. Consequently space and time measuring instruments distort so that, for example, the light waves emanating from a spark are always measured as spherical. We view the electron as an elementary particle of finite extension which is not subject to the Lorentz contraction. This places a further requirement on the measurement process in order to maintain the relativity postulate. The requirement is filled by the Heisenberg uncertainty principle which prevents measurements from using the size of the electron as a standard of length for measuring the relativistic distortion of space-time measuring instruments. ($\Delta p \Delta x = mc2r_0 = 2\alpha\hbar < \hbar$). This implies that any elementary particle cannot be appreciably heavier than the π mesons, have a size $\sim r_0$ and still be stable. For example the proton decays virtually into proton and neutral pion in about the time it takes a photon to traverse the nucleon (10^{-23} sec). On the other hand, the relatively stable π and μ mesons with intermediate mass $\approx 2/\alpha$ times that of the electron are consistent if their size is not appreciably larger than that of the electron.

D6. Relativistic Particle Theories with Interaction.* L. L. FOLDY, *Case Institute of Technology.*—The question of whether it is possible to construct a Lorentz invariant quantum theory of a system of permanent particles interacting without the mediation of a field is considered. This requires the construction of a representation of the fundamental commutation relations of the inhomogeneous Lorentz group satisfying certain conditions.[1] A system of noninteracting particles is defined by a representation which is the product of irreducible representations of the Wigner-Bargmann type, one for each particle. The infinitesimal generators are in this case simply added. Interaction is then introduced by adding interaction terms to the generators of time displacements and Lorentz transformations so that the resultant representation is no longer a product representation.[1] The general forms of the interaction terms are determined by expanding in powers of $1/c^2$ (c = velocity of light) and successively integrating the commutation relations. From the results to order $1/c^2$, the general form of the solution can be inferred and coincides with a result of Bakamajian and Thomas.[2] The usefulness and significance of such theories requires further study.

* Work aided by support of the U. S. Atomic Energy Commission.
[1] P. A. M. Dirac, Revs. Modern Phys. 21, 392 (1949).
[2] B. Bakamajian and L. H. Thomas, Phys. Rev. 92, 1300 (1953).

D7. Pairing Plus Long-Range Force for Single Closed Shell Nuclei. L. S. KISSLINGER* AND R. A. SORENSEN,† *University Institute for Theoretical Physics, Copenhagen.*—The low energy properties of nuclei are calculated using a model which combines certain important features of the unified nuclear model and the independent particle model with a two-body residual interaction. The residual interaction used has two parts, a pairing force and a long range part.[1,2] Calculations are done for nuclei with a major closed proton or neutron shell, $A > 48$, for various values of the two strength parameters, using single particle levels taken from experiment. In each region the calculated energy levels and spins agree in considerable detail with systematic experimental data. In addition, the even-odd-A mass difference, the electromagnetic transition rates, and other properties are calculated and compared to experiment. The approximate $1/A$ dependence of the parameters is consistent with a volume force.

* Research Corporation Fellow on leave from Western Reserve University.
† National Science Foundation Postdoctoral Fellow, now at Columbia University.
[1] A. Bohr and B. Mottelson (to be published).
[2] S. T. Belyaev, Kgl. Danske Videnskab. Selskab. Mat.-fys. Medd. 31, No. 11 (1958).

D8. Free-Free Transition Probability of the Negative-Hydrogen Ion. T. OHMURA, *National Research Council of Canada.*—It is shown that the free-free transition matrix element of the negative hydrogen ion can be expressed, within an accuracy of the order of one percent, in terms of the S phase shifts of the electron-hydrogen atom scattering. Hence the continuous absorption coefficient due to the free-free transition including the exchange and the correlation effects in the S states can be calculated from a knowledge of the S phase shifts alone, which include the exchange and the correlation effects. If we use the phase shifts adopted by Bransden *et al.*,[1] the new values of the free-free coefficient are of 40~50% less than the ones computed by Chandrasekhar and Breen,[2] who used the Hartree functions without exchange. A detailed tabulation will be developed for wide ranges of the wavelength and the temperature of the gas.

[1] Bransden *et al.*, Proc. Phys. Soc. (London) A71, 877 (1958).
[2] Chandrasekhar and Breen, Astrophys. J. 104, 430 (1946).

D9. Giant Dipole Resonance State of O^{16}.* M. K. PAL AND Y. C. LEE, *University of Maryland.*—A collective state for O^{16} which involves opposite displacements of neutrons and protons, together with spin excitation, has been generated by applying the operator $\Sigma_i(\mathbf{r}_i \times \boldsymbol{\sigma}_i)\tau_3(i)$ to the ground state Ψ_0. This state has an odd parity and a total angular momentum, spin and isotopic spin each equal to unity. The mixture of this state with the "giant dipole resonance" state, $\Sigma_i z_i \tau_3(i)\Psi_0$, via the spin-orbit interaction has been considered to understand the result obtained by Elliott and Flowers,[1] namely the electric dipole matrix element is divided in

comparable proportions between the two highest states resulting from an exact diagonalization.

* Work supported in part by the Office of Naval Research.
[1] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **A242**, 57 (1957).

D10. Low-Energy Photopion Production from Pions and Neutral-Pion Decay.* HOW-SEN WONG, *Lawrence Radiation Laboratory.*—The Mandelstam representation[1] is applied to the problem of photopion production from pions. It is shown that a set of homogeneous coupled integral equations may be obtained for the partial-wave amplitudes. Since these equations do not have a unique solution, a subtraction for the p-wave amplitude is needed and an unknown parameter Λ is introduced. At present, we cannot relate Λ to other known quantities or to the new parameter λ introduced by Chew and Mandelstam[2] in the π-π interaction. However, a method to determine Λ by extrapolation of the cross section for $\gamma+p \rightarrow \pi^+ + \pi^- + p$ is proposed.[3] An application of $\pi+\gamma \rightarrow 2\pi$ to calculate the decay rate of neutral pions will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] S. Mandelstam, Phys. Rev. **112**, 1344 (1958).
[2] G. F. Chew and S. Mandelstam, Theory of the Low-Energy Pion-Pion Interaction, UCRL-8728 (April, 1959).
[3] G. F. Chew and F. E. Low, Phys. Rev. **112**, 1635 (1959).

D11. Theory of Allowed and Forbidden Transitions of Muon Capture Reaction. MASATO MORITA, *Columbia University,* AND AKIHIKO FUJII, *Purdue University.*—The transition rate of the muon capture reaction $\mu^- + (A,Z) \rightarrow \nu + (A,Z-1)$ where the final nuclear state has definite spin and parity is given in the spherical representation. The induced pseudoscalar interaction and the interaction due to an assumption of the conserved vector current are taken into account. The forbiddenness of the muon capture reaction is defined. The number of the reduced nuclear matrix elements which belong to each forbiddenness is 9, 16, and 14 for the allowed, the first forbidden and the higher forbidden transitions, respectively. The transition rate is reduced by a factor of approximately 100, for two units increase of the forbiddenness, if the atomic number and energy of the neutrino are constant. The contribution of the higher order transition to the lower one is less than 0.1%. The muon caputre rate by C^{12} is calculated for various assumptions. In some cases, the neglected terms in reference 1 are 8–12%. The knowledge of the $(\mu_p - \mu_n)$ term can be obtained only if we know the sign of C_P/C_P'.

[1] A. Fujii and H. Primakoff, Nuovo cimento (to be published); H. Primakoff, Revs. Modern Phys. **31**, 802 (1959).

D12. $\mu \rightarrow e+\gamma$ Decay and the Intermediate Charged Vector Boson Theory. PHILIPPE MEYER* AND GEORGE SALZMAN,† *CERN.*—The $\mu-e-\gamma$ vertex is calculated in the intermediate charged vector boson theory as a function of the square of the four momentum of the photon. Consistency arguments show that the boson anomalous magnetic moment should be taken equal to zero. The result is then specialized to a real photon. The experimental branching ratio,

$$\rho = (\mu \rightarrow e+\gamma)/(\mu \rightarrow e+\nu+\bar{\nu}) = (1.2 \pm 1.5) \times 10^{-6},$$

fixes the cutoff value at less than one fifth the intermediate boson mass. It is concluded that this theory does not reasonably account for the experimental data, no matter how massive the boson is assumed to be.

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D13. Hyperfine Splitting Effects in the Capture of Polarized μ^- Mesons. H. ÜBERALL, *Carnegie Institute of Technology.*—Mu-mesic atoms with spin exist in two incoherent hyperfine states[1] which decay with two different lifetimes. If the muons still possess a polarization upon arrival in the K shell, the neutrons emitted in the capture process are predicted to show an asymmetry which differs from the one expected from spinless nuclei, even after averaging over the hyperfine states. This originates from a polarization of the capturing proton induced when the hyperfine interaction flips the muon spin. The effect has been ignored in earlier papers on neutron asymmetries,[2] and is investigated by us for muon capture in hydrogen, in deuterium, and in complex nuclei treated by the Schmidt model. We find a Fermi-Gamow-Teller interference which distinguishes between $V+A$ and $V-A$ coupling. We also calculate gyromagnetic ratios in the mesic atom ground states.

[1] Bernstein, Lee, Yang, and Primakoff, Phys. Rev. **111**, 313 (1958).
[2] Shapiro, Dolinsky and Blokhintsev, Nuclear Phys. **4**, 273 (1957); Huang, Yang, and Lee, Phys. Rev. **108**, 1340 (1957); L. Wolfenstein, Nuovo cimento **7**, 706 (1958); **8**, 882 (1958); H. Überall and L. Wolfenstein, Nuovo cimento **10**, 136 (1958).

FRIDAY MORNING AT 10:15

Tomlinson Hall

(C. S. SMITH, JR., presiding)

Luminescence; Semiconductors I (Compounds)

E1. Preparation and Properties of SiC Crystals Which Exhibit Edge Emission. D. R. HAMILTON, LYLE PATRICK, AND W. J. CHOYKE, *Westinghouse Research Laboratories.*—Crystals of SiC have been prepared in a high temperature furnace[1] after the fashion of Lely. Under ultraviolet excitation the purest of the crystals exhibit an extensive, strongly polarized edge emission, i.e., at 77°K the greatest photon energies are only slightly less than 2.91 ev, the energy gap of SiC. It is found that the level of chemical impurities, for example nitrogen, iron, or aluminum, cannot greatly exceed 10^{17} atoms/cm^3 if edge emission is to be displayed. There does not at present appear to be any direct correlation between the edge emission and any specific impurity. The samples are predominantly of 6H polytype, although small admixtures of 15R polytype do occur. The presence of the traces of 15R apparently does not influence the results discussed in the following abstract.

[1] D. R. Hamilton, J. Electrochem. Soc. **105**, 735 (1958).

E2. Polarized Edge Emission Spectra of SiC. W. J. CHOYKE, D. R. HAMILTON, AND LYLE PATRICK, *Westinghouse Research Laboratories.*—The photoluminescence of relatively pure hexagonal SiC crystals includes a strongly polarized edge emission. Two distinct patterns of edge emission lines have been found, but never in the same crystal. In each pattern the edge emission includes several narrow lines and a number of wider bands spaced at regular energy intervals of 0.03 ev, suggestive of a vibrational interaction. The 0.03-ev energy

interval is much less than the energies of the lattice optical phonons. A model for the luminescence center is suggested in which the transitions are to vibrational levels of the ground state. Optical resolution of $\sim 10^{-3}$ ev was obtained through the use of photon counting techniques which will be described.

E3. Probable Luminescence Center for Edge Emission of SiC. LYLE PATRICK, W. J. CHOYKE, AND D. R. HAMILTON, *Westinghouse Research Laboratories.*—The narrow edge emission lines in SiC, assumed to result from transitions to the lowest vibrational level of the ground state, have a half-width of only 0.0016 ev at 77°K, i.e., about $kT/4$. This fact is used to rule out those mechanisms for the production of polarized light which depend on the structure of the valence or conduction bands. Other sources of polarized radiation are considered, of which a center consisting of a nearest neighbor donor-acceptor pair is thought to be the most probable. Certain degrees of polarization characteristic of such a center are derived, and shown to be consistent with experimental results. Intrinsic recombination radiation was looked for but not found.

E4. Preparation and Semiconducting Properties of Single Crystal Boron Phosphide. B. STONE AND D. HILL, *Monsanto Chemical Company.*—Single crystals of cubic boron phosphide with dimensions up to about 3 mm × 1 mm × 1 mm, have been grown by two techniques: (1) by slow cooling of a melt containing dissolved boron and phosphorus; and (2) by the vapor phase reaction of boron compounds with phosphorus vapor. Crystals obtained by these techniques are transparent and red in color. The x-ray diffraction powder pattern of this material is identical to that reported for cubic boron phosphide by other workers.[1,2] Elemental analyses give boron to phosphorus ratios of 1.0 within the limits of accuracy of the analytical method. The forbidden gap of boron phosphide has been reported[3] to be 5.9 ev. Thermoelectric power measurements show that both n- and p-type material has been prepared. Measurements of Hall coefficient on p-type material indicate a carrier concentration of about 10^{18} carriers/cm³. The room temperature hole mobility is about 300 (cm²/volt sec) for this material. Point contact rectification has also been observed.

[1] P. Popper and T. A. Ingles, Nature **179**, 1075 (1957).
[2] Perri, Laplaca, and Post, Acta Cryst. **11**, 310 (1958).
[3] F. V. Williams, paper presented at American Chemical Society Meeting, Boston, Massachusetts, April, 1959.

E5. Infrared Cyclotron Resonance Absorption of Electrons in InSb. E. D. PALIK AND G. S. PICUS, *U. S. Naval Research Laboratory.*—The cyclotron resonance absorption of n-type InSb in magnetic fields up to 65 kilogauss has been measured as a function of photon energy at temperatures of approximately 300°K, 80°K, and 25°K. The absorption is found at photon energies between 0.03 ev and 0.05 ev. Measurements with circularly polarized light confirm that the absorption is due to electrons. At constant magnetic field the absorption at room temperature has a sharp edge at high energy, but persists to the lowest energies measured. At lower temperatures the band sharpens, and two peaks separated by 0.0033 ev at 64 kilogauss are found. The low-energy peak is the less intense. A third, broad peak at still lower energy also appears. The mean effective mass determined from the position of the strongest peak is 0.017 m_0. The sample has an electron concentration of 10^{15}/cc and a mobility of 267 000 cm²/volt-sec at liquid nitrogen temperature. Because of the relatively high temperatures of the measurements, it is not expected that appreciable freeze-out of carriers into donor centers occurred, and therefore the effects observed are due to conduction band electrons. The structure observed may be the result of electronic transitions starting from Landau levels other than the lowest one.

E6. Electrical Properties of n-type CdSe. SHAUN DEVLIN, *Clevite Corporation.*—The conductivity and Hall effect of degenerate n-type samples of CdSe doped with gallium were measured from 77°K to 800°K. The carrier concentration changed slowly over this temperature range. The electron mobility is about 500 cm²/volt sec at room temperature and varies at T^{-1} at high temperatures. Impurity scattering becomes significant just below room temperature in the highly doped samples ($N_D = 1 \times 1 \times 10^{19}$ atom/cm³) and the mobility asymptotically approaches a constant value at low temperatures.

E7. Infrared Absorption in P-Type AlSb. W. J. TURNER AND W. E. REESE, *I.B.M., Poughkeepsie.*—The optical absorption constants of AlSb have been determined from transmission and reflection data on polished monocrystalline samples in the spectral region of 0.7–38 microns at 300 and 78°K. The results obtained for p-type samples will be discussed. A 1.6-micron band exists for which the absorption constant varies linearly with hole concentration. Previously Blunt *et al.*[1] observed this band in more impure AlSb and Braunstein[2] has identified this as an intervalence band transition from a spin orbit split off band. Our data are consistent with this model. Structure exists near the intrinsic edge and lattice bands are present at 11.2, 13.5, 16.5, 22.5, 28, and 29.6 microns. The AlSb samples were provided by the Compound Semiconductor Research Group of Battelle Memorial Institute.

[1] Blunt, Frederikse, Becker, and Hosler, Phys. Rev. **96**, 578 (1954).
[2] R. Braunstein, Bull. Am. Phys. Soc. Ser. II, **4**, 133 (1959).

E8. Diffusion of Cd and Zn in GaAs.* BERNARD GOLDSTEIN, *RCA Laboratories.*—Radioactive Cd^{115} and Zn^{65}, obtained from the Oak Ridge National Laboratory, have been used as tracers to study the diffusion of these elements in single crystal GaAs. In the temperature range from 868°C to 1149°C the diffusion of Cd into GaAs from the vapor phase followed an erfc curve, and the diffusion constants followed the customary equation $D = D_0 e^{-E/kT}$ where $E = 2.40$ ev and $D_0 = 0.05$ cm²/sec. A lower limit to the solid solubility was found to be $\sim 10^{19}$/cm³. The diffusion of Zn from the vapor phase, however, could not be described by a single diffusion constant. The penetration profiles, after an initial region, dropped sharply below the erfc curve, thus confirming the behavior reported by Allen and Cunnell,[1] The Zn concentrations were as high as 10^{20}/cm³. Hall measurements made on samples which had been diffused to saturation showed that the Zn, in these concentrations, occupied substitutional sites and was essentially all ionized. When the Zn was made to diffuse from thin, electroplated layers at temperatures below 800°C, well-behaved penetration profiles were obtained giving diffusion constants about two orders of magnitude larger than those of Cd and with an activation energy the same as that for Cd.

* This work was supported by the Electronics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.
[1] J. Allen and F. Cunnell, Nature **182**, 1158 (1958).

E9. Anisotropic Diffusion of Copper into Bismuth Telluride. R. O. CARLSON, *General Electric Research Laboratory.*—A marked difference has been found between the penetration of radioactive copper parallel to and perpendicular to the cleavage planes in Bi_2Te_3. $D_{\parallel} = D_0 \exp -(E/kT) = 0.0034 \times \exp(-0.21/kT)$, $D_{\perp} = 0.071 \exp(-0.80/kT)$. At room temperature, $D_{\parallel} \sim 10^{-6}$ cm²/sec, while extrapolated $D_{\perp}$ is more than eight decades lower at $\sim 3 \times 10^{-15}$ cm²/sec. Minute cracks, except perhaps on an atomic scale, are not believed

responsible for the fast parallel diffusion. The fast parallel diffusion can be rationalized on the basis that in this direction, between adjacent tellurium layers, the copper moves through a region of relatively weak electrostatic bonding forces and large layer spacing. In any other direction, covalent and ionic bonding between tellurium and bismuth atoms would make penetration more difficult. Zener's theory[1] is shown to give a reasonable fit to the D_0 values, requiring a negligible entropy term for parallel diffusion and a small entropy term, approximately the Boltzmann factor k, for perpendicular diffusion.

[1] C. Wert and C. Zener, Phys. Rev. **76**, 1169 (1949); C. Zener, in *Imperfections in Nearly Perfect Crystals* (John Wiley & Sons, Inc., New York, 1951), pp. 289–314.

E10. Thermoelectric Properties of Bi_2Te_3–Bi_2Se_3 Alloys.* W. C. MYERS AND R. T. BATE, *Battelle Memorial Institute.*—The electrical resistivity, thermoelectric power, and thermal conductivity of Bi_2Te_3 and alloys with Bi_2Se_3 were measured in the temperature range between 68°K and room temperature. The figure of merit was determined from the difference between adiabatic and isothermal resistivity measurements.[1] All measurements were made potentiometrically, and a square wave current was used to obtain isothermal data. Results show that alloying greatly decreases the thermal conductivity of Bi_2Te_3 at low temperatures. The thermal conductivity of an n-type Bi_2Te_3 sample with 5% addition of Bi_2Se_3 shows a maximum of 0.02 w/cm°K in the vicinity of 110°K and drops to 0.016 w/cm°K at 68°K. This is in contrast to the behavior of unalloyed material for which the maximum is about 0.6 w/cm°K and occurs at about 9°K.[2,3] The electrical resistivity of this sample is proportional to $T^{1.4}$ over the temperature range studied, (compared with a $T^{2.7}$ dependence for pure material)[2] with a room temperature value of 2.2×10^{-3} ohm-cm. The figure of merit reaches a maximum of 2.4×10^{-3} °K^{-1} at about 195°K and decreases with decreasing temperature to 0.85×10^{-3} °K^{-1} at 68°K.

* Supported by the Office of Naval Research.
[1] T. C. Harman, J. Appl. Phys. **29**, 1373 (1958).
[2] C. B. Satterthwaite and R. W. Ure, Jr., Phys. Rev. **108**, 1164 (1957).
[3] MacDonald, Mooser, Pearson, Templeton, and Woods, Phil. Mag. **4**, 433 (1959).

E11. Infrared Properties and Effective Ionic Charge of CdTe.* P. FISHER AND H. Y. FAN, *Purdue University.*—Samples of CdTe[1] with electron concentration $\sim10^{15}$ cm^{-3} were studied. Reflection measurements were made on thick samples in the range 2–190 microns. At short wavelengths, the reflectivity was approximately constant, ~21%. From transmission interference fringes a refractive index of 2.67 was obtained in the range 8–14 microns. This value is consistent with the reflectivity value. The effect of lattice vibration was observed at long wavelengths. The reflectivity dropped to a minimum of 5% at 58 microns, then rose to a maximum of 78% at 68 microns. It fell toward longer wavelengths, reaching ~29% at 130 microns after which little variation was observed. The value 29% is consistent with the low frequency value of dielectric constant, 11.0 ± 0.3, reported by de Nobel. Analysis of the reflectivity curve yielded: $\Delta\epsilon=3.5$, $\omega_0=2.64\times10^{13}$ sec^{-1} for the fundamental optical mode, a damping factor $\gamma=0.055\omega_0$, and an effective ionic charge $e^*=0.76e$. Transmission measurements showed two additional absorption bands, one at 35 microns and the other at 40 microns. The former appears to be the second harmonic of the fundamental optical mode.

* Work supported by the Office of Naval Research.
[1] We are indebted to Dr. Shilladay of the Battelle Memorial Institute for supplying the CdTe.

E12. Anomalous Skin Effect in Antimony.* ARTHUR J. GREENFIELD, GEORGE E. SMITH,† AND A. W. LAWSON, *University of Chicago.*—Recent high-frequency surface resistance measurements have been made on plane, electropolished surfaces of zone refined, single crystal antimony at 2°K. Under extreme anomalous skin effect conditions, measurements perpendicular to the trigonal axis permit a partial determination of the hole band structure. Making use of the de Haas-van Alphen,[1] cyclotron resonance,[2] and specific heat[3] data, and assuming charge conservation and a six ellipsoid model for both bands, one can calculate the Fermi energy, $E_h=0.012$ ev and mean effective mass, $m_h'=1.5m_0$ of the holes. By further identifying a set of unexplained d.H.-v.A. oscillations as being caused by holes, one obtains $m_2=9.6m_0$. Surface resistance measurements then indicate $m_1=1.7m_0$. Experiments on other orientations to determine m_3 and m_4 are in progress.

* This paper placed on Friday by request.
† Now at Bell Telephone Laboratories.
[1] Shoenberg, Phil. Trans. Roy. Soc. (London) **A245**, 1 (1952).
[2] Dexter and Datars, Conference on Electronic Properties of Metals, Geneva, New York, 1958.
[3] Wolcott, Phys. Rev. (to be published).

FRIDAY AFTERNOON AT 2:15

Tomlinson Hall

(T. G. ECK presiding)

Semiconductors II: Silicon and Germanium

G1. Analysis of Diffusion of Phosphorus on Dislocations in Silicon.* KURT HUBNER AND WILLIAM SHOCKLEY, *Shockley Transistor Corporation.*—A grain boundary contributes solute diffusion current and accumulation equaling slabs of normal material W_D and W_0 thick, respectively.[1] Letting v be the velocity along the grain boundary and 2θ the dihedral angle of an isoconcentration surface, a new relationship results: $2D/v\ \tan\theta=W_D\sin^2\theta-W_0$ with D the bulk diffusion constant.[2] Plotting $(v\tan\theta)^{-1}$ *vs* $\sin^2\theta$ gives $W_D/2D$ and $W_0/2D$ for slope and intercept. Data obtained on diffusion runs up to 149 hr at 1200°C using beveling and staining techniques for phosphorus on a 7° tilt boundary in silicon gave $W_D/2D=4.4$ hr/μ, corresponding to $W_D=17.6$ μ, so that each dislocation contributes 360 000 times the bulk diffusion current of a column one Burgers vector square. This could occur if W_D arose from the edge row of atoms on the extra half-plane with concentration enhancement of 600-fold each for phosphorus and vacancies. This model gives $W_0\cong300$ A; consistent experimental data showing only that $W_0<1$ μ.

* Research supported by Air Force Cambridge Research Center.
[1] See Shockley, Roberts, and Hoerni [Bull. Am. Phys. Soc. Ser. II, **2**, 202 (1957)] for fuller definitions.
[2] For a review of other methods see *Solid State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, Inc., New York, 1959), Vol. 8, p. 459, and references.

G2. Localized Excess Reverse Currents in Silicon *P-N* Junctions.* ADOLF GOETZBERGER AND WILLIAM SHOCKLEY, *Shockley Transistor Corporation.*—Silicon *P-N* junctions

sometimes show excess reverse currents below avalanche breakdown. The *V-I* characteristics of these which have a soft appearance were investigated at different temperatures. At low temperatures this current varies as V^n where n is between 4 and 7 over seven decades of current. This soft current is conjectured to be on account of Zener tunneling at localized high fields such as might be produced at precipitated metals in the space charge region. Confirmation of this hypothesis was furnished by diffusion and precipitation of several metals in Si which contained previously hard junctions. Cu, Fe, and Mn were found to soften the junction. It was also shown that this soft current is not caused by a surface effect by a potential plotting method. The equipotentials in the surface of a diode show that all the current is flowing through a single spot in the junction. This type of soft breakdown is distinguishable from that resulting from localized avalanche breakdown which is associated with light emission; the latter rises much more steeply. Both currents may be limited by ohmic spreading resistances.

* Research supported by Air Force Cambridge Research Center.

G3. Faraday Rotation and Ellipticity in Semiconductors as a Function of Conductivity and Magnetic Field at 1- and 3-cm Wavelength. J. K. FURDYNA AND S. BROERSMA, *Northwestern University.*—Standard theory gives the microwave propagation constant for magnetized semiconductors as a function of carrier type, mobility μ, conductivity, collision time, and dielectric constant. We measured the Faraday rotation at room temperature for fields B up to 20 kilogauss, in n- and p-silicon with resistivities from 40 to 0.5 ohm cm. Results for n-Si agree well with the calculated values if the Hall mobility is used, except in the case of resistivities lower than 2 ohm cm at 3-cm wavelength. For p-Si best agreement is obtained when the drift mobility is used. At 77°K n-Si and n-Ge show a maximum in the *Rotation vs B* curve for $\mu B \approx 1$ (mks units), beyond which rotation drops steadily as B is raised. Similar behavior is observed for the ellipticity. These results check with exact data furnished by a digital computer. Rotation and ellipticity in samples of pure InSb (10^{14}–10^{16} carriers/cc) observed at 77°K and 195°K manifest an oscillatory behavior in B. Preliminary results show rotation extrema at $\mu B = 5$, 7, 11, and 19.

G4. Effect of Compensation on Impurity Band Conduction in Silicon.* R. K. RAY AND H. Y. FAN, *Purdue University.*—Impurity conduction in silicon samples doped with B, Al, and Ga between $5\times10^{16}-5\times10^{17}$ cm^{-3} have been investigated. The activation energy, E, corresponding to resistivity variation increased with impurity concentration, consistent with a model of Coulomb interaction between the majority and some compensating impurities. However, E seemed to depend also on the doping impurity. Al-doped samples gave about twice higher E and Ga-doped samples had about three times higher E than B-doped samples of comparable acceptor concentrations. By means of heat treatment, known amounts of compensating donors were added and the compensation originally in the samples were determined from changes in the extrinsic Hall coefficient. The original compensation ranged 3–5% in the B-doped, ~10% in the Al-doped, and 0.1–0.3% in the Ga-doped samples. For the Al-doped and B-doped samples E decreased with addition of compensation but not as fast as expected. The Ga-doped samples had initially $E>20$ Mev, much higher than is expected from the model of Coulomb interaction. Addition of ~1% compensation reduced E by nearly 50%. The results indicate some ion-pairing between original compensating donors and Ga, and a more random distribution of donors added by heat treatment.

* Work supported by a Signal Corps contract.

G5. Diffusion Rate of Li in Si.* E. M. PELL, *General Electric Research Laboratory.*—The diffusion rate of Li in Si has been measured previously.[1–3] The present results represent an attempt to determine more accurately this rate and also the magnitude of the experimental error. An accurate value is needed for the understanding of the diffusion mechanism and also for the determination of Li impurity binding energies where these are obtained from diffusion or drift experiments. An outdiffusion technique which permits a particularly simple check of boundary conditions yields $D=(2.17\pm0.05)\times10^{-6}$ cm^2/sec at 800°C ±5°C and $D=2.4\times10^{-5}$ at 1350°C ±5°C. Combined with the latest values obtained by ion drift in an np junction in the range of 25°C to 125°C, this yields $D=(2.5\pm0.2)\times10^{-3}\exp[(0.655\pm0.01)q/kT]$, which is in substantial agreement with some of the earlier results. The experimental results extend over nine decades in D.

* Supported by the U. S. Air Force Cambridge Research Center.
[1] C. S. Fuller and J. A. Ditzenberger, Phys. Rev. 91, 193 (1953).
[2] C. S. Fuller and J. C. Severiens, Phys. Rev. 96, 21 (1954).
[3] J. P. Maita, J. Phys. Chem. Solids 4, 68 (1958).

G6. Contact Potential Difference Measurements on (111) Silicon Surfaces Prepared by Cleavage in High Vacuum.* R. E. SIMON, *RCA Laboratories.*—The contact potential differences between silicon surfaces prepared by cleavage at room temperature in high vacuum (5×10^{-10} mm Hg) and a polycrystalline tungsten ribbon have been measured by the Kelvin method. The tungsten ribbon was flashed at 2400°K less than 15 sec before the silicon was cleaved. Since the measurements were made within three minutes after the silicon was cleaved and the cpd was changing by less than 0.0005 v/min, the results could be extrapolated to the time of cleavage to get the cpd between clean silicon and clean tungsten. The work function of 1.2 ohm-cm n-type silicon was found to be 4.76±0.03 v in approximate agreement with measurements reported on argon-bombarded surfaces. Variations from this value of several tenths of a volt were observed in more heavily doped samples.

* Work supported by U. S. Army, Signal Research and Development Laboratory.

G7. Transport Properties of Compensated Degenerate Germanium. I. Electrical Resistivity and Thermoelectric Power. J. F. GOFF AND N. PEARLMAN, *Purdue University.*—The effect of gallium compensation of antimony doped germanium single crystals on the electrical resistivity ρ and the thermoelectric power Q has been observed between 1.2 and 80°K. The total impurity concentration for the compensated and non-compensated samples was between $1–6\times10^{18}$ cm^{-3}; the latter had compensation ratios N_D/N_A of about 0.85. The electrical resistivity increased upon compensation and showed impurity conduction usually, however, without exhibiting a definite activation energy in the low-temperature region. For the non-compensated sample, Q had a minimum at 80°K ($Q_{\min}=-0.35$ mv/deg). Between 80 and 7°K $|Q|\alpha T^{0.5}$; below 7°K $|Q|\alpha T^{1.6}$. Upon compensation $|Q|$ increased by an order of magnitude over the whole temperature range and showed apparent phonon-drag behavior with maxima in the 30–50°K range. If $|Q|$ is extrapolated downward from just below its maximum, the observed values are lower than the extrapolated curve for $N_D<3\times10^{18}$ cm^{-3} but higher than this curve for $N_D>3\times10^{18}$ cm^{-3}.

G8. Transport Properties of Compensated Degenerate Germanium. II. Thermal Conductivity. N. PEARLMAN AND J. F. GOFF, *Purdue University.*—Degenerate n- or p-type Ge has lower thermal conductivity k than pure Ge[1] at temperatures below 100°K, the ratio being as small as 10^{-2} at 2°K for a concentration of 2×10^{18} Sb atoms per cm^3. This extra

thermal resistance was investigated by measuring k on the compensated samples described in the preceding abstract. Below its maximum at about 20°K k is enhanced in the compensated samples, but by a factor smaller than the decrease in exhaustion carrier concentration. The phonon mean-free-path has the same T dependence (decreasing with T) in the more lightly doped of the compensated samples, but it is independent of T in the most impure compensated sample. Compensation increases k just above its maximum also, but it becomes the same in the more impure of the compensated samples as in the uncompensated by 50°K, the common curve lying below the intrinsic and joining the latter at about 150°K. In the most pure compensated sample, however, k is only slightly below the intrinsic curve above 30°K. These observations are difficult to interpret in terms of simple additive carrier concentration and impurity atom resistivity components.

[1] Carruthers, Geballe, Rosenberg, and Ziman, Proc. Roy. Soc. (London) **A238**, 502–514 (1957); Fagen, Goff, and Pearlman, Phys. Rev. **94**, 1415 (1954).

G9. Impurity Conduction in *P*-Germanium with Constant and Controlled Compensation.* H. FRITZSCHE AND M. CUEVAS, *University of Chicago.*—In studying impurity conductivity as a function of impurity separation the degree of compensation should remain fixed. A fixed 3 to 1 ratio of gallium to arsenic impurities was introduced in germanium by neutron bombardment and subsequent nuclear transmutation. The concentration of gallium, N, ranged from 8×10^{14} to 2×10^{16} per cc. Between 1°K and 3°K the resistivity, ρ, can be expressed as $\rho=C\exp(\epsilon/kT)$, where ϵ changes slowly with N between 3.5×10^{-4} and 5.9×10^{-4} ev. The following expressions fit C (ohm-cm) equally well: $C=0.5\exp(3.95\times10^{8}d^{\frac{1}{3}})$, $C=1.12\times10^{-3}d^{-1}\exp(4.03\times10^{8}d^{\frac{1}{3}})$, and $C=1.43\times10^{-52}N^{3}\exp(2.79\times10^{8}d)$, where $d=2(3/4\pi N)^{\frac{1}{3}}$ cm. Using the current theories of impurity conduction and the above expressions one obtains 80 A for the radius of the impurity ground state wave function. This is a factor of two larger than expected.

* Work supported in part by a National Science Foundation Grant and a U. S. Atomic Energy Commission contract.

G10. Diffusion of Hydrogen in Germanium.* R. C. FRANK, *General Motors Research Laboratories*, AND J. E. THOMAS, JR., *Wayne State University.*—Single crystal germanium diffusion specimens were prepared by a technique similar to that previously used for silicon by Van Wieringen and Warmoltz.[1] The hollow cylindrical specimens were sealed at one end and attached to a mass spectrometer at the other. By surrounding the thin cylinder with hydrogen gas and observing it diffuse through into the mass spectrometer, permeation rates and diffusion coefficients were measured in the temperature range of 800 to 910°C. The excellent agreement between diffusion coefficients measured by the "delay time" and decay curve methods indicates that trapping effects by lattice defects were small or non-existent. At 800°C the diffusion coefficient was 4.7×10^{-5} cm²/sec and the solubility was 6.0×10^{13} atoms/cc. The activation energy for diffusion is 8.7 ± 0.8 kcal/g atom and the heat of solution is 52.8 ± 1.4 kcal/g atom. The permeation rate was found to vary as the square root of the gas pressure which indicates that the hydrogen exists in the germanium lattice as hydrogen atoms or ions.

* Supported in part by the U. S. Air Force.
[1] A. Van Wieringen and N. Warmoltz, Physica **22**, 849–865 (1956).

G11. Thermal Diffusivity of Germanium.* B. ABELES, G. D. CODY, AND D. S. BEERS, *RCA Laboratories.*—By using Angström's method, the thermal diffusivity κ/C (thermal conductivity/specific heat) of germanium has been measured from 30° to 750°C. By using published[1] values of κ, the specific heat of germanium has been determined as a function of temperature. At the high temperature end both C_v and C_p rise above the Dulong-Petit value of $3R$. This effect is believed to be caused by anharmonicity of the lattice.

* This work was supported in part by BuShips and in part by Air Force.
[1] B. Abeles, J. Phys. Chem. Solids **8**, 340 (1959).

Invited Paper

G12. Electron Hole Recombination at Multilevel Impurities in Germanium. G. K. WERTHEIM, *Bell Telephone Laboratories.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Bingham 103

(J. G. DAUNT presiding)

Metals; Cryogenics

H1. Production of Single Crystal Copper Films at Low Temperatures.* ARTHUR YELON AND R. W. HOFFMAN, *Case Institute of Technology.*—A method is described for the production of single crystal films of copper at temperatures as low as −40°C. This method utilizes the epitaxy of copper on rocksalt. A thin layer of copper is evaporated on the salt at a rate of about 6 A/sec at 350°C. Then a thick layer is evaporated at the low temperature. At −40°C good results have been obtained with an evaporation rate of 12 A/sec. Films grown by this method have been examined using x-ray and etching techniques. It was found that some of these films had single crystal regions of 1 mm diameter and larger. These crystallites had [100] directions within 1° to a normal to the film surface.

* Supported by the U. S. Atomic Energy Commission and the National Carbon Company.

H2. Stress Anisotropy in Thin Metal Films.* J. D. FINEGAN AND R. W. HOFFMAN, *Case Institute of Technology.*—Measurements were made of the ratio of minimum stress to maximum stress in the plane of thin metal films. The tension in the films caused sufficient bending of the thin glass substrates that Newton's rings were observed when the substrates were placed on an optical flat.[1] The stress ratio was obtained from

the shape of the Newton's rings with the theory of bending of plates. The directions of maximum and minimum stress were mutually perpendicular. The magnitude and orientation of the anisotropy is correlated with the direction of incidence of the depositing atoms during the formation of the film.

* Supported by the U. S. Atomic Energy Commission and National Carbon Company.
[1] J. D. Finegan and R. W. Hoffman, J. Appl. Phys. **30**, 597–598 (1959).

H3. Low-Temperature Specific Heats of the Group IV-A Metals. G. D. KNEIP, JR., AND J. O. BETTERTON, JR., *Oak Ridge National Laboratory.**—The specific heats of titanium, zirconium, and hafnium were found to obey the relation $C=\gamma T+\beta T^3$ from 1.1 to 4.5°K within the experimental error. As for other transition metals, the electronic term is large and for the Group IV-A metals decreases with increasing atomic number indicating a progressively larger degree of electronic interaction in the sequence titanium, zirconium, hafnium. The Debye temperatures decrease with increasing atomic mass, as would be expected from the central force model; however, the ratios of the Debye temperatures indicate that the average atomic force constant for hafnium is some 50% larger than for titanium and zirconium in agreement with the unusually small atomic volume of hafnium.

* Operated for the U. S. Atomic Energy Commission by the Union Carbide Corporation.

H4. Elastic Constants of Ordered and Disordered Cu_3Au from 4.2-300°K. J. A. RAYNE, P. A. FLINN, AND G. M. MCMANUS, *Westinghouse Research Laboratories.*—The elastic constants of ordered and disordered Cu_3Au have been measured from 4.2–300°K. The room temperature data are in good agreement with previous work. At liquid helium temperatures, the ordered material, with $S=0.95$, gives $c_{11}=1.893\pm0.015\times10^{12}$ dyne cm^{-2}, $c_{12}=1.319\pm0.015\times10^{12}$ dyne cm^{-2}, $c_{44}=0.736\pm0.002\times10^{12}$ dyne cm^{-2}. The corresponding value of Debye temperature is $\theta_{\text{ordered}}=283.8\pm3.5$°K, which compares very well with the calorimetric figure of 285 ± 2°K. For the change in Debye temperature on ordering, the elastic data give $\Delta\theta=2\pm7$°K, while the calorimetric data give $\Delta\theta=7\pm4$°K. The elastic constants for the disordered alloy indicate that the Fermi surface is less distorted than that in pure copper.

H5. Low-Temperature Elastic Constants of Magnesium Alloys. S. EROS, *Case Institute of Technology.*—The elastic constants of magnesium alloys have been measured at liquid nitrogen and helium temperatures. The purpose was to look for effects which are predicted to be associated with the initiation of electron overlap and which can only be seen at low temperatures. The possible effect which is experimentally observed in the plot of elastic constant against composition is much smaller than the effect predicted by the rigid band model of Reitz and Smith. It is concluded that if overlaps are initiated in the electron/atom range 1.996–2.02, the rigid band model is inadequate to account for the elastic constant behavior without considerable second order elaboration. A reasonable reassignment of energy and effective mass parameters in the rigid band model is sufficient to account for the composition dependence of all three shear constants, and for the initial rate of change with composition of the electronic specific heat.

H6. Electrical Resistivity Study of Solid Solutions of Beta-AuCd and Beta-AgCd Alloys. F. ROTHWARF, *Frankford Arsenal*, AND L. MULDAWER, *Temple University.*—Resistivity data as a function of temperature and composition will be presented for solid solutions of beta-AuCd and beta-AgCd alloys. The data will be analyzed in terms of Debye temperatures and Matthiessen's rule. Residual resistivity measured at 4.2°K will be presented as a function of composition.

H7. Phase Transformations in Solid Solutions of Beta-AuCd and Beta-AgCd Alloys. L. MULDAWER, *Temple University*, AND F. ROTHWARF. *Frankford Arsenal.*—Electrical resistivity measurements have been used to determine the temperature T_0 of martensitic transformation in these alloys. Increasing the AgCd concentration lowers T_0. The 47.5% Cd alloys undergo a diffusionless transformation from body centered cubic to orthorhombic on cooling, T_0 for beta AuCd $\cong$345°K, and T_0 for beta AgCd $\cong$110°K. It is assumed that Ag and Au occupy the same set of lattice sites, and that Cd always occupies the other set. This allows the possibility of an order-disorder transformation involving Ag and Au. Evidence for this ternary ordering is found in the residual resistivity of the alloy containing equal numbers of Ag and Au atoms.

H8. Low-Temperature Internal Friction in fcc and bcc Metals. L. J. BRUNER,* *University of Chicago.*—An investigation of the contribution of dislocation relaxation phenomena to the anelasticity of various fcc and bcc metals and alloys at temperatures from 4.2°K to 300°K is reported. Fcc materials studied include copper, aluminum, and aluminum −0.25 at. % copper. Bcc systems investigated are iron, niobium, and β brass. Dislocation relaxation or Bordoni peaks are observed in pure copper and aluminum in accordance with the work of previous investigators.[1] Strain aged aluminum −0.25 at. % copper alloys show no evidence of such peaks, nor are they observed in pure iron. A peak is observed in niobium, but it is not believed to be associated with dislocation relaxation. Low temperature internal friction peaks are observed in β brass; their origin is not established. A new mechanism is proposed for dislocation relaxation in which the essential feature is the thermally activated motion of paired partial dislocations between vacancy pinning points.

* Now at I.B.M. Watson Laboratory.
[1] P. G. Bordoni, J. Acoust. Soc. Am. **26**, 495 (1954).

H9. Thermoelectric Power of Magnesium Ternary Alloys. E. I. SALKOVITZ AND E. W. KAMMER, *U. S. Naval Research Laboratory.*—A study[1] on the electron transport properties of dilute magnesium binary alloys has demonstrated that the magnitude and sign of such properties were dependent on the electron concentration of these alloys. It was demonstrated that the electronic contribution to the thermoelectric power was a linear function of the electronic concentration in these alloys. This behavior was interpreted in terms of Brillouin zone overlap. An investigation has been undertaken to determine to what extent the model may be applied to dilute ternary alloys of magnesium. Thermoelectric power measurements have been made on a series of MgAgIn alloys containing approximately equal dilute concentrations of silver and indium. These alloys thus have an average electron concentration of 2. Therefore, it should be expected that the zone overlap which manifested itself in the MgIn binary alloys by an inflection point in the curve of thermoelectric power *versus* composition, should be suppressed. This was found. Indeed, the thermoelectric power curve for the ternary strongly resembles that of the MgCd series.

[1] Salkovitz, Schindler, and Kammer, Phys. Rev. **105**, 887, 1549 (1957).

H10. Dispersion Strengthening Analysis of Cermets. JOHN M. WOULBROUN, *Watertown Arsenal*, AND BENNETT BOVARNICK, *Raytheon Company.*—A recent theoretical advance for analysis of precipitation dispersion strengthened systems is examined in detail. The theory is based on the strengthening or hardening by entrapment of dislocation at internal particles. The WC-Co system was selected for analysis as a mechanically dispersed cermet. The internal stresses in WC-Co were calculated for cobalt content up to 25% by weight. The calculated stresses were treated by methods of the theory. The critical shear stress in WC-Co varied from 98 300 psi to

200 000 psi for volume fractions of WC from 60.0% to 86.6% with a maximum of 228 000 psi at 66.0%. Results were compared with findings reported for precipitation dispersed systems and indicate good agreement between mechanically dispersed and precipitation dispersed systems. The theoretical technique for analysis of dispersion strengthened systems is shown to be valid for either precipitation or mechanical methods of dispersing the hard phase and its range of applicability has been extended from small volume fractions of dispersed phase to volume fractions of 0.87 or 92 weight percent of WC in cobalt.

H11. Possible Superfluidity of He^3 in He^3-He^4 Mixtures.* ADAM BECHER, *Ohio State University.*—The CMS criterion[1] for superfluidity of a system of strongly interacting fermions has been employed to study the properties of liquid He^3 at low temperatures. The trial function used consisted of a solution of the Schroedinger equation for a δ-function modified two-body potential. Arguments will be presented for the choice of this function. The interatomic He^3-He^4 potential was approximated by a square well plus a hard core with parameters chosen to fit the phase shifts given by De Boer. The results obtained show no superfluidity for He^3 at normal density, in agreement with CMS, but show possible superfluidity at densities less than or equal to at least that corresponding to a Fermi momentum of 0.59 A^{-1}. Therefore, if it is assumed that in He^3-He^4 mixtures He^3 behaves as a Fermi gas, but with an effective mass of 2, it is found that the He^3 component may become superfluid provided its concentration is below 40% of normal density. However, the probable breakdown of the theory at low densities and the fact that the expected transition temperature may lie within the phase separation region makes it unlikely that such a transition could be experimentally observed.

* Research supported in part by the National Science Foundation.
[1] Cooper, Mills, and Sessler, Phys. Rev. (to be published).

H12. Velocity of Sound in Liquid He^3 at High Pressures.* H. FLICKER† AND K. R. ATKINS, *University of Pennsylvania.*—The velocity of 14 Mc/sec sound in liquid He^3 was measured at pressures up to 9 atmos in the temperature range 1.2 to 3.2°K. A few measurements were also made in the gas just above the critical temperature. A possible phonon contribution to the thermal coefficient of expansion of the liquid is discussed.

* Supported by the National Science Foundation.
† Union Carbide Fellow. Now With RCA Laboratories, Princeton.

H13. Investigation of the Energy Gap in Superconducting Lead Films from Low-Temperature Measurements of the Penetration Depth. M. P. SARACHIK, R. L. GARWIN, AND E. ERLBACH, *I.B.M. Watson Laboratory and Columbia University.*—Recent determinations[1] of the temperature variation of the penetration depth λ have shown deviations from the predictions of the Gorter-Casimir two fluid model and are in agreement with the energy gap theories of Lewis[2] and BCS.[3] A measurement of the variation of λ with temperature T in the region of lower reduced temperatures, where λ varies but little with T, yields information about the energy gap at 0°K. The variation of λ with T is obtained in the present experiment by measuring the penetration of a magnetic field through thin superconducting lead films. Since a change in λ of 0.2 A can be measured, the low reduced temperature region can be accurately investigated. The results do not agree with the BCS predictions based on an energy gap of $3.5\ kT_c$ at 0°K. Better agreement is obtained for larger energy gaps.

[1] A. L. Schawlow and G. E. Devlin, Phys. Rev. **113**, 120 (1959).
[2] H. W. Lewis, Phys. Rev. **102**, 1508 (1956).
[3] Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).

H14. Superconducting Electromagnets.* S. H. AUTLER, *Lincoln Laboratory, M.I.T.*—Joint use of liquid helium and magnetic fields occurs in many experiments on the properties of solids, as well as certain devices such as solid-state masers. For such applications, electromagnets have been built having coils wound with superconducting wire. These magnets are compact and fit inside the Dewar containing liquid helium and the sample. Since no heat is generated in superconducting coils, liquid helium is not consumed beyond that initially required to cool the magnet. Furthermore, a very small power supply suffices to energize the magnet. The fields generated by superconducting "air-core" coils is limited to the critical field, H_c, at which superconductivity is quenched. We have made niobium wire solenoids which produced fields greater than 4 kilogauss. By setting up a closed superconducting circuit, persistent currents have been maintained in these solenoids for many hours and the magnetic field used to operate a 1420 megacycle maser at 2000 gauss. Magnetic fields much higher than H_c are obtained by using a ferromagnetic core in combination with superconducting coils. Fields in excess of 9 kilogauss have been obtained between the pole-faces of one such magnet. The maximum attainable field should be limited only by saturation of the core.

* The work reported in this paper was performed with the joint support of the U. S. Army, Navy, and Air Force.

FRIDAY AFTERNOON AT 2:15

Physics 301

(E. F. SHRADER presiding)

Reactions of Transmutation II; Fission; Neutron Physics

J1. Location of $3s_{\frac{1}{2}}$ Levels in Odd-Neutron Nuclei and of O^+ Levels in Even-Even Nuclei in the Mass 80-130 Region.* BERNARD L. COHEN AND ROBERT E. PRICE, *University of Pittsburgh.*—The systematics of proton angular distributions from (d,p) stripping reactions was studied in the mass 110 region; processes in which $l_n=0$ are clearly distinguishable from all others as they are the only ones which rise sharply in the forward direction (8–15°). By locating peaks with this characteristic in the bombardment of even neutron nuclei in the mass region 80–130, the position of the $3s_{\frac{1}{2}}$ single particle levels in these nuclei were traced. Where targets are even-even, only a single, strongly excited $l_n=0$ level is found; in odd-Z targets, there is a closely spaced group of levels; no other $l_n=0$ levels are found within 4 Mev of these. The binding energy of a $3s_{\frac{1}{2}}$ neutron, corrected for symmetry energy, is constant throughout the region; this is difficult to explain using the usual model of a single particle in a well. The implications for the Wilkinson theory of the photonuclear giant resonance will be discussed. Similar experiments on odd neutron target nuclei with $s_{\frac{1}{2}}$ ground states gives the location of O^+ levels in the residual even-even nuclei. New O^+ levels in the triplet region were found in Cd^{114} (1.14 Mev) and Cd^{112}

(1.23, 1.43), and many higher O^+ levels were found in these and in the Sn isotopes.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the National Science Foundation and by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

J2. Nuclear Levels of Odd-A Nuclei for Odd Neutron Numbers 99 to 107. J. W. MIHELICH, *University of Notre Dame,** AND B. HARMATZ AND T. H. HANDLEY, *Oak Ridge National Laboratory.*†—Isotopes of Hf have been bombarded with protons in the ORNL 86-in. cyclotron and the resulting neutron deficient isotopes of Ta have been studied with permanent magnet spectrographs. A number of level schemes have been postulated for odd A nuclei of neutron number 99 to 107 employing the foregoing data and previously published data.[1] Speculations may be made as to positions of intrinsic levels,[2] moments of inertia, and relative gamma ray transition probabilities.

* Supported by U. S. Atomic Energy Commission.
† Operated by the Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.
[1] Strominger, Hollander, and Seaborg, Revs. Modern Phys. 30, 585 (1958); and Harmatz, Handley, and Mihelich, Phys. Rev. 114, 1082 (1959).
[2] B. R. Mottelson and S. G. Nilsson, Mat.-fys. Skr. Danske Videnskab Selskab. 1, No. 8 (1959).

J3. Cross Sections for Some (n,p) and (n,α) Reactions for E_n from 12.4 to 17.8 Mev. BERNARD D. KERN, *University of Kentucky.*—Cross sections for the reactions $Al^{27}(n,p)Mg^{27}$, $Al^{27}(n,\alpha)Na^{24}$, $P^{31}(n,\alpha)Al^{28}$, $Ti^{48}(n,p)Sc^{48}$, and $Mn^{55}(n,\alpha)V^{52}$ have been measured for neutron energies from 12.4 to 17.8 Mev. The activation technique[1] was employed. A Zr-T target was used in the production of the neutrons, a $Li^6I(Eu)$ scintillation counter was used to monitor the neutrons, and a NaI(Tl) scintillation counter was used to count the gamma rays emitted by the activated material. The cross sections are observed to decrease smoothly through this neutron energy interval, by about a factor of two. Tentative cross sections at the neutron energy of 14.4 Mev: $P^{31}(n,\alpha)Al^{28}$, 155 mb; $Mn^{55}(n,\alpha)V^{52}$, 45 mb; and $Ti^{48}(n,p)Sc^{48}$, 15 mb. The first two values are in agreement with the earlier measurements of Paul and Clarke.[2]

[1] Kern, Thompson, and Ferguson, Nuclear Phys. 10, 226 (1959).
[2] E. B. Paul and R. L. Clarke, Can. J. Phys. 31, 267 (1953).

J4. Coulomb Excitation of Heavy Nuclei with 20-Mev Alpha Particles. STEPHAN BERKO,* *Institute of Theoretical Physics, Copenhagen.*—The external 20-Mev alpha beam of the Copenhagen cyclotron was used to Coulomb excite high lying states in heavy nuclei. Nuclei from Ta to U were studied. High backgrounds were encountered, probably on account of nuclear reactions with light impurities and to (α,n) reactions in the target nucleus. Because of the high Coulomb excitation cross sections at this bombarding energy, it was possible to excite the first level of Bi^{209} (930 kev). The experiment yields $eB(E2)=0.007\pm30\%$ in units of $e^2\times10^{-48}$ cm^4, 5.9 times the independent particle value, using $h_{9/2}$ for the ground state and $f_{7/2}$ for the excited state; this corresponds to an "effective charge" for the proton of $2.4e$. To reduce the large background due to (α,n) reactions, an alpha-gamma coincidence setup was constructed and tested. Results with Th^{232}, using this technique, will be presented indicating that the $2+$ state at 790 kev corresponds to a β vibrational band. Spectra of Au and U will also be discussed.

* A. P. Sloan Research Fellow, 1958–59; now at University of Virginia.

J5. Fission of Radium by 11- to 22-Mev Protons.* ROBERT L. WOLKE, *University of Florida.*—Planar targets of radium-impregnated gold were interleaved with Au and Al foils and the stack was bombarded normally with 22-Mev protons in the external beam of the ORNL 86-in. cyclotron. The ranges of Pd^{112} and Sr^{91} fission fragments recoiling from the Ra target were determined by isolating these nuclides radiochemically from each of several differential and integral Au absorbers and measuring their activities. The ranges in mg Au/cm^2 at 11 and 20 Mev, respectively, are Sr^{91}: 10.3 and 11.0; Pd^{112}: 8.18 and 9.11. The total fission yield and the yields of Sr^{91} and Pd^{112} were determined as a function of proton energy by degrading the beam with Al absorbers. The ratios $\sigma(22\text{ Mev})/\sigma(14\text{ Mev})$ were found to be 3.47 for total fission, 4.62 for Sr^{91}, and 8.11 for Pd^{112}, indicating that the symmetric peak predominates at higher energies. The range data will be discussed and related to possible mechanisms for the fission of radium.

* Part of this work was done under a subcontract with the Electronuclear Research Division of Oak Ridge National Laboratory, and under a Research Participation contract with the Oak Ridge Institute of Nuclear Studies.

J6. Study of Fission Induced by Heavy Ion Bombardment.* A. R. QUINTON, H. C. BRITT, W. J. KNOX, AND C. E. ANDERSON, *Yale University.*—Thin targets of gold have been bombarded with 160-Mev oxygen ions and fission fragment energy spectra observed at 10° intervals in the laboratory system. The pulse height response of the proportional counter detector was calibrated[1] by means of a Cf^{252} source. Under the assumption of symmetric fission from a system of 204 nucleons, transformation to the center of mass reveals a spectrum, peaking at 75 ± 5 Mev and 30 Mev full width at half maximum, independent of the angle of observation. The total fission cross section is 1.9 ± 0.3 barns. The angular distributions are energy independent, symmetric about 90°, and can be fitted to a $1/\sin\theta$ curve from about 30° to 150°. Beyond 150° the observed distribution is lower than $1/\sin\theta$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. C. D. Milton and J. S. Fraser, Phys. Rev. 111, 877 (1958).

J7. Measurement of η for U^{233}, U^{235}, and Pu^{239} by the Manganese Bath Technique.—R. L. MACKLIN, G. DESAUSSURE, J. D. KINGTON, AND W. S. LYON, *Oak Ridge National Laboratory.*—The absolute value of η for U^{233}, U^{235}, and Pu^{239} was measured directly by a method of total absorption which involves relative counting and some minor corrections. A thermal neutron beam is introduced in the center of a 1-meter-diam sphere filled with a solution of manganous sulfate in water. The beam is first made to activate the manganese bath directly, then it is totally absorbed in a sample of the isotope under investigation whose fission neutrons then activate the bath. The ratio of the two activities is equal to η, except for small corrections. The values obtained corrected to 2200 m/sec were: η for $U^{233}=2.30\pm0.02$, η for $U^{235}=2.07\pm0.02$. The small corrections to be applied to the value of η for Pu^{239} have not yet been evaluated.

J8. Absorption Cross Section of U^{235} from 10 to 175 kev. J. H. GIBBONS, P. D. MILLER, R. L. MACKLIN, AND J. H. NEILER, *Oak Ridge National Laboratory.*—A pulsed accelerator and a gamma total absorption detector have been used to compare the absorption cross section of U^{235} to the capture cross section of indium in the energy range from 10 to 400 kev using $Li^7(p,n)Be^7$ neutrons from a thin Li^7 metal target. A measurement of the shape of the indium capture cross section relative to the known shape of the $B^{10}(n,\alpha\gamma)Li^7$ cross section also has been made in the region from 10 to 140 kev. This latter measurement of the shape of σ_a of U^{235} has been normalized to the known value of $\sigma_a=\sigma_f(1+\alpha)=1.77$ barns at 175 kev, and the behavior of σ_a of U^{235} thus determined from 10 to 175 kev. Derived values of $\alpha=\sigma_c/\sigma_f$ also will be presented.

J9. Total Neutron Cross Section of Pa^{231}.* F. B. SIMPSON, W. H. BURGUS, O. D. SIMPSON, AND J. E. EVANS, *Phillips Petroleum Company.*—The total cross section for Pa^{231} was

measured from 0.01 ev to 5.0 ev, using the Materials Testing Reactor fast chopper with resolutions from 0.24 to 0.50 μsec/meter. In this energy region resonances were observed at 0.395, 0.495, 0.743, 1.25, 1.97, 2.79, 3.49, 4.13, 4.36, 4.53, and 5.05 ev. The average level spacing is 0.99 ev per spin state. These measurements give for the thermal total cross section a preliminary value of 211±20 barns. The resonance absorption integral (for neutrons with energies >0.1 ev) has tentatively been assigned a value of 1200 barns, with a contribution of more than 80% from the 0.395-ev resonance. These measurements were made with samples (up to 1.3 g/cm² of protactinium oxide) prepared from 0.558 g of Pa_2O_5 that had been carefully purified by Harold W. Kirby of Mound Laboratory.

* Work done under the auspices of U. S. Atomic Energy Commission.

J10. Total Neutron Cross Section of B^{10} in the Range $0.018 \leq E \leq 0.4$ ev. H. W. SCHMITT, R. C. BLOCK, AND R. L. BAILEY, *Oak Ridge National Laboratory.*—A precise determination of the total neutron cross section of B^{10} has been made by means of transmission measurements of boron samples highly enriched in B^{10}. The ORNL fast chopper time-of-flight spectrometer was used to obtain results in the neutron energy range $0.018 \leq E \leq 0.4$ ev. It is found that the total cross section of B^{10} in this energy range follows the relation $\sigma_t(\text{barns}) = (639 \pm 5)/E^{\frac{1}{2}}(\text{ev})$. The total cross section of B^{10} for neutrons of energy 0.0253 ev (velocity = 2200 meters/sec) is found to be 4017±32 barns.

J11. Thermal Neutron Mean Lifetime in Water.* FRED HOLZER† AND MARSHALL F. CROUCH, *Case Institute of Technology.*—The mean lifetime of thermal neutrons in a large cylindrical water moderator for which escape amounts to less than 5% has been measured. The value obtained for τ is 211.9±2.4 μsec, giving a value of 0.321±0.004 barns for the thermal neutron-proton capture cross section, in substantial agreement with previous measurements. Care was taken to minimize the errors usually associated with this type of experiment; in particular, the higher harmonics of the neutron distribution were eliminated by liberating, at selected points inside the moderator, the correct number of neutrons to establish only the fundamental mode of the neutron distribution. Since a BF_3 counter on the axis of the cylinder is used to sample the neutron density, the perturbing influence of this counter must be evaluated. This is accomplished by calculating the neutron distribution as a solution to an eigenvalue problem with variable boundary conditions. Three approximation calculations will be presented which allow the counter perturbation to be determined and which permit the fundamental mode for the geometry used to be calculated.

* This work was supported by the U. S. Atomic Energy Commission.
† Now at the Lawrence Radiation Laboratory, Livermore, California.

FRIDAY AFTERNOON AT 2:15

Electrical Engineering 322

(R. W. HOFFMAN presiding)

Invited Papers

K1. Interaction between Rotation and Vibration in Pyramidal XY_3 Molecules with a Special Reference to Phosphine. H. H. NIELSEN, *Ohio State University.* (30 min.)

K2. Energy Moment Method for Treating Certain Quantum Mechanics Problems with Particular Reference to the Asymmetric Rotator Problem. PAUL M. PARKER, *Michigan State University.* (30 min.)

Paramagnetic Resonance

K3. Effect of Silicon on the Electron Spin Resonance of Graphite. G. WAGONER AND L. S. SINGER, *National Carbon Company Research Laboratories.*—We have observed that graphite reacts with SiO_2 at temperatures as low as 300°C to produce a broadening of the electron spin resonance line. The degree of broadening depends upon the particle size of the SiO_2 and upon the particle size and crystallite size of the graphite. For a single crystal there was no observable broadening after a heat treatment with SiO_2 powder at 1200°C for one hour, whereas finely powdered graphite showed the effect after a few minutes at 300°C. These observations suggest that silicon, by forming a surface compound with graphite, provides an additional spin-lattice relaxation mechanism for the conduction electrons which are responsible for the resonance.[1] Similar broadening effects are observed with silicon carbide and with elemental silicon and germanium. In no case was there a change of total spin concentration. The resonance in graphite can, of course, be broadened simply by heat-treating in a quartz vessel and as a consequence, previous work on the spin resonance in graphite may require re-examination.

[1] G. Wagoner, Bull. Am. Phys. Soc. Ser. II, 4, 22 (1959).

K4. Spin Traps in π-Electron Radicals. HARDEN M. MCCONNELL, *California Institute of Technology.*—Conventional molecular orbital or valence bond calculations of the distribution of electron spin angular momentum in π-electron radicals may break down in the larger odd-alternate or negative ion hydrocarbon radicals due to a trapping of the spin in regions of elongated carbon-carbon bonds. Self-trapping of the spin in localized molecular regions is possible. Diffusion of the spin and its associated bond elongation through a molecule can give rise to a time dependent atomic orbital spin density matrix. Spin trapping may account for the otherwise anomalous low rate of spin exchange in large biradicals.[1]

[1] D. C. Reitz and S. I. Weissman, J. Chem. Phys. 27, 968 (1957).

K5. Electron Resonance of Polyene Radicals.* M. W. HANNA† AND HARDEN M. MCCONNELL,‡ *California Institute of Technology.*—Electron resonance line shapes in x-irradiated polycrystalline samples of conjugated polyene acids, $CH_3(CH{=}CH)_nCOOH$, have been studied as a function of the chain length, n, where $n = 1, 2, 4, 6$. The line shapes are approximately Gaussian and the peak-to-peak derivative line widths (gauss) are 8.7 ($n=1$), 21.5 ($n=2$), 31.9 ($n=4$), and 16.3 ($n=6$). The radicals producing the resonances are thought to be $\cdot CH_2(CH{=}CH)_nCOOH$. The narrowing of the resonance signal for the acid with thirteen unsaturated carbon atoms ($n=6$) is evidence for π-electron spin trapping, and

may also be associated with the bond alternation predicted by Ooshika,[1] and Longuet-Higgins and Salem.[2]

* Sponsored by the United States Public Health Service, the National Science Foundation, and the Office of Ordnance Research, U. S. Army.
† National Science Foundation Postdoctoral Fellow.
‡ Alfred P. Sloan Fellow.
[1] Y. Ooshika, J. Phys. Soc. Japan **14**, 747 (1959).
[2] H. C. Longuet-Higgins and L. Salem, Proc. Roy. Soc. (London) **251**, 172 (1959).

K6. Paramagnetic Resonance of Gd^{3+} in Yttrium Gallium Garnet. B. A. CALHOUN, J. OVERMEYER, AND M. J. FREISER, *IBM, Poughkeepsie.*—The paramagnetic resonance spectrum of Gd^{3+}, substituted for approximately 1% of the yttrium in single crystals of yttrium gallium garnet, has been observed at 24 000 mc at 4.2° and 77°K. In the garnet structure, Gd^{3+} ions occupy sites with very low symmetry (three perpendicular twofold rotation axes) which have six different orientations relative to the axes of the cubic unit cell. Each differently oriented Gd^{3+} ion produces seven resonances, but with the magnetic field parallel to the cubic [100], [110], and [111] directions, the spectra consist of 14, 21, and 14 lines respectively. These results can be interpreted in terms of the usual spin-Hamiltonian with nine crystal field operators appearing because of the low symmetry. The two second power operators, $D/2[S_z^2-\frac{1}{3}S(S+1)]$ and $3E[S_x^2-S_y^2]$ (x,y,z are the local symmetry axes), are sufficient to account for the general features of the spectrum, but the higher power crystal field terms are required to obtain quantitative agreement between the calculated and observed resonance fields. The significance of these crystal field terms and, particularly, their influence on the magnetic properties of gadolinium iron garnet will be discussed.

K7. Hyperfine Effects in the Paramagnetic Resonance of Color Centers in Germanium-Doped Quartz. J. A. WEIL, *Princeton University,* AND A. H. MORRIS AND J. H. ANDERSON, *University of Pittsburgh.*—Single crystals of quartz containing small amounts of germanium exhibit paramagnetic resonance after irradiation with x-rays. The spectra have been interpreted as resulting from electrons trapped on Ge atoms.[1] Two such centers are found; their EPR lines exhibit hyperfine structure, both giving 4 components but differing in their orientational properties. This structure was tentatively ascribed to the presence of alkali ions [presumably Na^{22}] located in the large c-axis channels present in quartz. Recent experiments making use of diffusion at *ca* 200°C in applied electric fields[2] have enabled us to replace the alkali ions originally present with Li^6. The 4-line structure disappears and is replaced by single lines having almost the same g tensors. From these results it is clear that the color centers indeed contain alkali ions as essential components. Details of the hyperfine structure will be discussed.

[1] J. H. Anderson and J. A. Weil, J. Chem. Phys. **31**, 427 (1959).
[2] R. C. Vogel and G. Gibson, J. Chem. Phys. **18**, 1094 (1950).

FRIDAY AFTERNOON AT 2:00

Strosacker Auditorium

(G. E. UHLENBECK presiding)

First Fruits of the Satellite Explorer VI

L1. High-Energy Radiation Experiment. PETER MEYER, *University of Chicago.* (30 min.)
L2. Observations of the Van Allen Radiation Zones during Geomagnetic Storms. J. R. WINCKLER, *University of Minnesota.* (30 min.)
L3. Whistler Mode and VLF Noise Experiments. R. A. HELLIWELL, *Stanford University.* (30 min.)
L4. Geomagnetic Field Measurements. C. P. SONETT, *Space Technology Laboratories.* (15 min.)
L5. Scintillation-Counter Measurements. ALAN ROSEN, *Space Technology Laboratories.* (15 min.)
L6. Theoretical Implications of the Charged Particles Trapped in the Geomagnetic Field. EUGENE PARKER, *University of Chicago.* (30 min.)

FRIDAY EVENING AT 6:00

Lounge, Wade Park Manor Hotel

Cocktail Party

FRIDAY EVENING AT 7:00

Lincoln Room, Wade Park Manor Hotel

(G. E. UHLENBECK presiding)

Banquet of The American Physical Society

Speakers to be announced

LATE ON FRIDAY EVENING

Party at Carling Brewery (see Preamble)

SATURDAY MORNING AT 9:30

Strosacker Auditorium

(R. S. SHANKLAND presiding)

Antiprotons and Hypernuclei

Invited Papers

N1. Some Aspects of the Antiproton Annihilation Process. SULAMITH GOLDHABER, *University of California, Berkeley.* (30 min.)

N2. Status of Experimental Hypernuclear Physics. R. LEVI SETTI, *University of Chicago.* (30 min.)

N3. What Can Be Learned from Hypernuclei. R. H. DALITZ, *University of Chicago.* (30 min.)

N4. Lifetime of Light Hyperfragments. W. F. FRY, *University of Wisconsin.* (15 min.)

N5. Hyperfragments from Capture of Negative *K* Mesons in Helium. M. M. BLOCK, *Duke University.* (15 min.)

SATURDAY MORNING AT 9:30

Bingham 103

(DUDLEY WILLIAMS presiding)

Invited Paper

P1. Resonant Beam Extraction from Sector-Focused Cyclotrons. H. G. BLOSSER, *Michigan State University.* (30 min.)

Nuclear Apparatus; Nuclear Magnetic Resonance and Hyperfine Structure

P2. University of Illinois Variable Energy Spiral Ridge Cyclotron.* SANTIMAY CHATTERJEE,† AVIVI I. YAVIN, AND JAMES S. ALLEN, *University of Illinois.*—The University of Illinois cyclotron has been reconstructed to accelerate protons from 4 to 15 Mev, deuterons from 7 to 14 Mev, He^3 from 11 to 37 Mev, and alpha particles from 15 to 27 Mev. The machine uses strong focusing[1] provided by spiral ridges on the pole faces. The required magnetic field configuration is obtained by using four spiral shims on each pole face and five sets of concentric field coils. The shims are terminated at the center of the 43-in.-diameter pole-face by a circular disk of iron 6 in. in diameter. The maximum measured flutter is about 7%. The machine has one dee and a dummy dee. Four focusing slits have been placed on the dee and four others on the dummy dee. The effects of the slits and the details of the machine will be reported. Both protons and deuterons have been brought out to the radius of 19 in.

* This research was supported in part by the Office of Naval Research.
† On leave from Saha Institute of Nuclear Physics, Calcutta University.
[1] Symon, Kerst, Jones, Laslett, and Terwilliger, Phys. Rev. **103**, 1837 (1956).

P3. Nuclear Magnetic Resonance of Ta^{181}. LAWRENCE H. BENNETT, *National Bureau of Standards,* AND J. I. BUDNICK,* *I.B.M. Research Laboratory.*—We have observed the nuclear magnetic resonance absorption and dispersion of Ta^{181} in $KTaO_3$ in a magnetic field of 9947 oersteds at a frequency of 5.068 mc/sec. The measurements were made at the National Bureau of Standards on specimens provided by Dr. T. Dunne and Dr. G. Burns of the I.B.M. Research Laboratory. The interaction between the exceptionally large electric quadrupole moment of Ta^{181} and internal electric field gradients may be the reason that its resonance has not previously been observed. The cubic environment of tantalum in $KTaO_3$ overcomes this difficulty. The uncorrected value of the nuclear magnetic moment obtained from this resonance is (assuming a nuclear spin of 7/2) 2.340 ± 0.001 nm. There is no magnetic field dependence of the moment. The best previously available value of the Ta^{181} nuclear magnetic moment was computed by the use of the Goudsmit-Fermi-Segrè formula from the hyperfine spectrum of TaII as 2.1 ± 0.4 by Brown and Tomboulian[1] and more recently as 2.4 ± 0.2 by Murakawa.[2] The possible importance of chemical shifts in correcting our observed value of the magnetic moment will also be discussed.

* Supported in part by the Department of Defense.
[1] B. M. Brown and D. H. Tomboulian, Phys. Rev. **88**, 1158 (1952).
[2] K. Murakawa, Phys. Rev. **110**, 393 (1958).

P4. Some Observations on Fast Passage in a Multi-Level Spin System.* P. E. WAGNER, J. G. CASTLE, JR., AND P. F. CHESTER, *Westinghouse Research Laboratories.*—The $(-\frac{1}{2},\frac{3}{2})$ transition in pink ruby has been observed after adiabatic fast passage through the $(-\frac{1}{2},\frac{1}{2})$ and $(\frac{1}{2},\frac{3}{2})$ lines, when they were coincident and when they were separated. Simultaneous passage through the two coincident lines resulted in inversion of the $(-\frac{1}{2},\frac{3}{2})$ line. Sequential passage

through the same two lines when they were not coincident, in accordance with the suggestion of Siegman and Morris,[1] did not result in inversion of the $(-\frac{1}{2},\frac{1}{2})$ line. These results can be understood by considering the minimum inversion efficiency required in the two cases. For the case of sequential passage, the $(-\frac{1}{2},\frac{1}{2})$ and $(\frac{1}{2},\frac{3}{2})$ lines would each have to be inverted with an efficiency exceeding ~47%. (For three lines in sequence the minimum would be ~69%.) These values are larger than we have usually obtained in practice. Simultaneous passage, on the other hand, requires only an efficiency greater than zero, independent of the number of lines. The effects of cross-relaxation are also discussed and are shown to be much less troublesome in simultaneous passage than in sequential passage.

* Sponsored by the Air Force Cambridge Research Center.
[1] A. E. Siegman and R. J. Morris, Phys. Rev. Letters 2, 302 (1959).

P5. Application of Nonequilibrium Statistical Mechanics to Nuclear Spin Relaxation. ROBERT L. PETERSON, *Lehigh University.**—The equations of motion for the spin components of a system of interacting, distinguishable, spin-$\frac{1}{2}$ particles have been determined by using the master equation of nonequilibrium statistical mechanics. A representation is first determined in which the three system spin operators are nearly diagonal. The operators defined by retaining only the diagonal elements in this representation are asserted to correspond to the observable macroscopic spin components, and are called "macroscopic operators." A master equation is derived in this macroscopic representation by use of second-order time-dependent perturbation theory. In the derivation, use is made of the assumption (verified for a certain class of spin-spin interactions) that relaxation of the spin components is due to irregularities in the spin-spin interactions. The formalism is applied to a system of nuclei in a simple cubic structure, with dipolar interaction between nearest neighbors. The spin components transverse to an external magnetic field H_0 are found to relax with a time proportional to T^{-1}, T being the lattice temperature. The spin component in the direction of the field relaxes with a time proportional to $T^{-1}e^{H_0^2}H_1^2$, where H_1^2 is the mean square deviation of the "internal field" from its equilibrium value.

* Now at Case Institute of Technology. Work is supported in part by the Esso Education Foundation.

P6. Spin-Lattice Relaxation of Br in KBr above 300 K.* W. GILBERT CLARK, *Cornell University.*—The nuclear spin-lattice relaxation time of Br^{81} ($L=\frac{3}{2}$) in KBr has been measured in a field of 7800 gauss from 300°K to 750°K using pulse techniques. The quantity measured in this experiment is the sum of transition probabilities (W_2+W_3) where W_2 refers to the spin transition from $m=\frac{1}{2}$ to $m=\frac{3}{2}$ and W_3 from $m=-\frac{1}{2}$ to $m=\frac{3}{2}$. Some of the measured values of (W_2+W_3) are 8.33 ± 0.30 sec^{-1} at 300°K, 22.7 ± 1.0 sec^{-1} at 458°K, and 487 ± 18 sec^{-1} at 757°K. In the temperature range covered, the expected relaxation mechanism is the interaction of the nuclear quadrupole moment with phonons. Theoretical calculations of the temperature dependence of quadrupolar relaxation times have been published by van Kranendonk[1] and Khutsishvili.[2] These calculations predict a temperature dependence for the transition probabilities whose dominant terms vary as the second and fourth power of the temperature at high temperatures. The temperature dependence of the transition probabilities measured in this experiment does not fit the theoretical predictions.

* Supported in part by the Office of Naval Research.
[1] J. van Kranendonk, Physica 20, 781 (1954).
[2] G. R. Khutsishvili, Soviet Phys. JETP 4, 382 (1957).

P7. Nuclear Spin Relaxation in Liquid He^3.* R. H. ROMER,† *Duke University.*—The nuclear spin relaxation time, T_1, of He^3 nuclei in pure liquid He^3 at its saturated vapor pressure has been measured at temperatures between 0.8°K and 3.1°K, at static magnetic fields from 1560 gauss to 12 200 gauss, using Pyrex containers of various sizes. No dependence of T_1 on the static magnetic field has been observed. The measured relaxation times increase gradually from 300 sec at 0.8°K to 650 sec at 3.1°K. These results, which do not agree with T_1 measurements made elsewhere,[1-3] are in good agreement with relaxation times calculated from the short correlation time form of the Bloembergen, Purcell, Pound theory, making use of the diffusion coefficient data of Garwin and Reich.[1,4]

* Supported by the Office of Naval Research and the Office of Ordnance Research, U. S. Army.
† On leave from Amherst College, 1958–1959.
[1] R. L. Garwin and H. A. Reich, Phys. Rev. (to be published).
[2] Careri, Modena, and Santini, Nuovo cimento 13, 207 (1959).
[3] F. J. Low and H. E. Rorschach, post-deadline paper presented to the American Physical Society, April 30, 1959.
[4] R. L. Garwin and H. A. Reich, Bull. Am. Phys. Soc. Ser. II, 3, 133 (1958).

P8. Nuclear Magnetic Resonance Spectra of Halogenated Ethanes.* D. D. ELLEMAN, L. C. BROWN, AND DUDLEY WILLIAMS, *The Ohio State University.*—The magnetic resonance spectra of H^1 and F^{19} in ethyl fluoride, ethyl chloride, ethyl bromide, and various multiply halogenated ethanes have been investigated at room temperatures. Characteristic chemical shifts have been measured and spin-spin hyperfine structure has been observed. In measuring chemical shifts, a ten-percent solution of H_2O in D_2O was used as a reference for H^1 resonances, while a pure sample of octofluorocyclobutane was used for F^{19} resonances. It was found that the shielding constant $\delta=[(\nu-\nu_{ref})/\nu_{ref}]\times10^6$ had values in the range 3.2 to 4.4 for CH_2 protons; 0.8 to 1.1 for CH_2F protons, with slightly larger values for CH_2Cl and CH_2Br protons; and −0.6 to −0.2 for CF_2H protons. For F^{19} resonances, values of δ were larger and ranged from approximately 75 to 110 for CH_2F; −30 to +5 for CHF_2; and −73 to −48 for CF_3 groups. The shielding constant δ had slightly more negative values for F^{19} in CF_2Cl and CF_2Br groups than in CF_3. Values of the spin-spin coupling constants J were determined for various pairs of nonequivalent spin $\frac{1}{2}$ nuclei in each molecule.

* Work supported in part by the Office of Scientific Research, Air Research and Development Command.

P9. Precision Determination of the Hyperfine Structure of Atomic Hydrogen.* L. WILMER ANDERSON, FRANCIS M. PIPKIN, AND JAMES C. BAIRD, *Harvard University.*—The hyperfine structure of the ground state of atomic hydrogen has been measured by optical pumping. The apparatus has been previously described.[1] The interval was found to be $\nu_H=1420.405735\pm0.000020$ Mc/sec. The pressure shift of this frequency for various buffer gases has been determined. The results are the following: neon $+1.7\pm0.4$ cycles/mm Hg, argon -3.8 ± 1.0 cycles/mm Hg, helium $+3.1\pm1.0$ cycles/mm Hg, and molecular hydrogen -0.29 ± 0.10 cycles/mm Hg.

* This research supported in part by a grant from The Research Corporation.
[1] Anderson, Pipkin, and Baird, Phys. Rev. Letters 1, 229 (1958).

P10. Spin Resonance of Atomic Tritium at 4.2°K.* J. LAMBE, J. BAKER, AND I. SCARISBRICK, *The University of Michigan, Willow Run Laboratories.*—A method of radioactive decay has been used to prepare atomic tritium at liquid helium temperatures. In this method molecular tritium is frozen in a container as a small crystal of tritium or in a noble gas matrix. When one of the atoms of a tritium molecule decays, it becomes He^3, leaving behind the other atom of tritium. This atom can then be studied by conventional techniques of paramagnetic resonance. In our experiment, 1 cc at STP of tritium gas was used. This is 2.6 curies. The tritium emits a weak beta particle which is easily shielded. This amount was frozen out in a quartz tube at 4.2°K. This

amount of tritium will produce about 10^{11} atoms per second. It required about 5 minutes to begin measurements, at which time one should have 3×10^{13} spins. Two main hyperfine lines are observed with a separation of 542 gauss as one would expect for tritium. This signal increases steadily. A second small hyperfine group is observed with a spacing of 510 gauss. This group does not grow. It is believed to be due to a species, perhaps atomic hydrogen, present in the gas before the freezing. High microwave power satellites were not observed.

* This work supported by the Air Force Office of Scientific Research.

P11. Hyperfine Structure of the $^3P_2$ State and the Nuclear Electric Quadrupole Moment of Mg^{25}. A. LURIO, *IBM Watson Laboratory.*—The hyperfine structure of $Mg^{25}(I=\frac{5}{2})$ in its metastable $^3P_2$ atomic state has been measured by the atomic beam magnetic resonance method. A beam of Mg atoms in the ground $^1S_0$ state is bombarded by electrons just after they emerge from the oven. This excites one in several thousand atoms to the $^3P_2$ state. The beam is detected on a cesium coated surface by electron ejection. The four hyperfine structure intervals were measured and are $\Delta\nu(\ -\frac{1}{2})=567.28\pm0.02$ Mc/sec, $\Delta\nu(\frac{7}{2}-\frac{5}{2})=452.34\pm0.02$ Mc/sec, $\Delta\nu(\frac{5}{2}-\frac{3}{2})=329.05\pm0.02$ Mc/sec, $\Delta\nu(\frac{3}{2}-\frac{1}{2})=199.80\pm0.06$ Mc/sec. From these measured intervals the dipole and quadrupole coupling constants are computed to be $a=-128.45\pm0.02$ Mc/sec and $b=15.89\pm0.02$ Mc/sec. From the b coefficient the quadrupole moment of Mg^{25} is computed to be $Q=+0.14\times10^{-24}$ cm^2.

SATURDAY MORNING AT 9:30

Electrical Engineering 322

(J. K. MAJOR presiding)

General Physics

Q1. Photon-Counting Spectrometer for Absorption Studies in the 100 A-300 A Range.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—Although photon counting techniques have been used in the study of soft x-ray emission spectra, to date absorption measurements in the 100 A–300 A region have been carried out primarily by photographic photometry. In the interest of devising a more reliable scheme for the determination of absorption coefficients in this spectral region, a grazing incidence spectrometer was equipped with a Cu-Be photomultiplier (modified Dumont type 6291). In the present arrangement the multiplier position is such as to accept a narrow band of radiation centered at about 180 A. This position was chosen in order to utilize the Al $L_{2,3}$ emission band as a source of incident radiation. The photon beam from an aluminum target with a power input of 50 ma at 1 kv gives rise to a pulse count rate which is quite adequate for the comparison of beam intensities in connection with attenuation measurements. Moreover, even the relatively low intensity continuum emitted from target metals of intermediate atomic number appears to be a usable source in conjunction with photon counting schemes. Provision is also made for rotating the multiplier and the absorber independently. With this arrangement it will be possible to measure reflectivity and transmission.

* Research supported by the Office of Naval Research.

Q2. Soft X-Ray Bremsstrahlung from Metal Targets.* T. J. PETERSON, JR., AND D. H. TOMBOULIAN, *Cornell University.*—The intensity distribution in the continuous soft x-ray spectrum over the 80 A to 180 A wavelength region has been further investigated using methods previously reported.[1] Mg, Mn, Ge, Ag, and Au have been used as targets for the incident electron beam. The potential of the target has been successively taken at various values in the range 500–3000 v. The relative power radiated per unit wavelength interval has been found to vary as $1/\lambda^\alpha$ where the magnitude of α is dependent upon the choice of target voltage and material. For the above choices, the value of α has been found to lie in the range 1.8 to 3.6. Comments will be made concerning the correspondence between some of the results and the predictions of the Sommerfeld theory as presented in the numerical calculations of Kirkpatrick and Weidmann.[2]

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] T. J. Peterson, Jr., and D. H. Tomboulian, Bull. Am. Phys. Soc. Ser. II, 4, 263 (1959).
[2] P. Kirkpatrick and L. Weidmann, Phys. Rev. 67, 321 (1945).

Q3. Evapor-Ion Pump with Cartridge Evaporator.* A. L. MORSELL AND R. G. HERB, *University of Wisconsin.*—Evapor-ion pumps previously described[1] utilize a device which feeds titanium wire against a hot evaporator or into an electron beam. Many other methods for evaporating titanium have been tried recently. Titanium rods and sheets heated by electron bombardment, conduction current, or radiation all gave poor performance. The first successful evaporator not requiring a feeder consisted of a hollow cylinder formed of several layers of stranded wire with two strands of titanium and two of tantalum. The hollow cylinder was heated by electron bombardment from a filament running along the axis, and radiation shielding was provided by three outer concentric cylinders of tantalum. Evaporators of this type installed in a pump of 4½-in. diam and 13-in. length have given typical pumping speeds of 350 l/sec for nitrogen at a pressure of 8×10^{-8} mm of Hg, 560 l/sec for oxygen at 3.2×10^{-8}, and 175 l/sec for air at 7×10^{-7}. The lowest pressure reached while evaporating was 2×10^{-9} mm Hg. One evaporator was operated almost continuously for one month. During this time it pumped down from forepump pressure four times and appreciable quantities of gas were bled in for pumping speed data.

* Work supported by the National Science Foundation, by the U. S. Atomic Energy Commission, and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] R. H. Davis and A. S. Divatia, Rev. Sci. Instr. 25, 1193 (1954).

Q4. Decomposition of Polymer Water Ions. PAUL O. SCHISSEL, *National Carbon Company.*—Inghram and Gomer[1] observed polymer water ions mass spectrometrically when using a field ionization source. Beckey[2] showed that their form is $H_3O^+(H_2O)_n$ with $n=0, 1, 2, 3$. We observed the above and small signals at $n=4$ and studied the pressure and surface temperature dependence of the signals. The H_3O^+ signal is proportional to the water pressure while $H_3O^+(H_2O)$ increases only slightly faster than the pressure—indicating that the

latter is not formed via a gas phase ion-molecule reaction. Increasing the surface temperature decreased the higher masses relatively—indicating the "equilibrium" at the surface is shifted to a less polymerized state. Broad peaks occur which are due to decompositions of the form $H_3O^+(H_2O)_n \rightarrow H_3O^+(H_2O)_m$ + neutral remainder. The results for the latter reaction indicate a collision induced mechanism. Because the voltage gradient in the source is high, these peaks are widely distributed in momentum. The distribution gives a measure of collision probability as a function of distance from the surface. For unimolecular decompositions such observations could permit measurements of decay time intervals of $\sim 10^{-11}$ to 10^{-6} sec.

[1] M. G. Inghram and R. Gomer, Z. Naturforsch., **10a**, S863–872 (1955).
[2] H. D. Beckey, Sixth Field Emission Symposium (June, 1959), Natl. Bur. Standards, Washington, D. C.

Q5. Origin of the Green and Red Fluorescence Bands in Pure Single Crystal CdS. B. A. KULP AND R. H. KELLEY, *Aeronautical Research Laboratory.*—The fluorescence spectrum in the visible region of certain pure CdS single crystals under uv stimulation at −196°C consists of two groups of lines, one in a blue band and one in a green band,[1] as well as two broad bands in the red, one with a maximum intensity at about 7200 A[2] and another with a maximum at about 6050 A. The green and the 7200 A red bands are produced by electron bombardment with a threshold energy of 115 kev. If originally present the green band is removed by bombardment at any energy between 2.5 kev and 200 kev, while the 7200 A red band increases in intensity with bombardment above 115 kev. An experiment will be presented which shows that the ceuter for the green fluorescence is the sulfur interstitial atom. The center for the 7200 A red band is therefore the sulfur vacancy. The 6050 A red band is removed by electron bombardment with a threshold energy between 25 and 30 kev. An experiment which shows that this band is a result of cadminm interstitial atoms will be presented. The 27.5 kev threshold for radiation annealing indicates that about 0.55 ev is necessary to move a cadmium atom from one interstitial position to another.

[1] L. R. Furlong and C. F. Ravilious, Phys. Rev. **98**, 954 (1955).
[2] J. Lambe, Phys. Rev. **98**, 985 (1955).

Q6. Retrograde Electrophoresis in Xe+Hg. CARL KENTY, *General Electric Company.*—The transport of Hg toward the anode[1,2] of a discharge in Xe+Hg has been studied further under conditions of uniform Hg concentration. At Xe pressures in the range studied, 0.3 mm to 3 mm, and with Hg at 40°C a dc current can be found (~1 amp in 1 mm Xe+Hg in a 34 mm i.d. tube) at which there is no electrophoresis; below this current the Hg flows as expected toward the cathode, but above this current it flows toward the anode. The observed relative intensity of the Xe lines increases with the current; it is assumed that a fraction f of the ions are Xe ions and that this fraction increases with the current. This would, beyond a certain current, allow the flow of neutral Hg anodeward under the impacts of electrons, considering the large Ramsauer cross section of Hg, to exceed the flow of Hg as Hg^+, or a complex Hg ion, to the cathode. Reasons for the increase of f with current will be discussed, and the effect of striations.

[1] C. Kenty, Bull. Am. Phys. Soc. Ser. II, **3**, 82 (1958).
[2] L. B. Loeb, J. Appl. Phys. **29**, 1369 (1958).

Q7. Electron Scattering by Thin Foils for Energies below 10 kev. HELMUT KANTER, *Westinghouse Research Laboratories.*—The transmission (η_T) of electrons through thin films of C, Al_2O_3, Al, Cu, Ag, and Au, together with their distribution in angle and energy, were measured in a spherical retarding potential analyzer. The distributions were characterized by average and most probable scattering angle, average and most probable fractional energy loss, etc. The dependence of these variables on initial energy (E_p), film thickness, and material was investigated. For sufficient film thickness, the transmitted energies, the scattering angles, and η_T can be represented as universal functions of the reduced energy E_p/E_c where E_c is the critical E_p for the onset of transmission. Direct relations exist between η_T, scattering angles, and energy losses, which are independent of E_p and film thickness for the complete range of scattering from small angle scattering to total diffusion. The dependence of η_T and average fractional energy loss on Z is consistent with published results on backscattering coefficient and energy loss for thick layers.[1] Range-energy relations are almost independent of Z when the range is measured in mass per unit area. Results for the scattering angle and energy loss as functions of E_p and film thickness reveal that existing theories are inadequate for this energy range.

[1] E. J. Sternglass, Phys. Rev. **95**, 345 (1954).

Q8. Efficiency of the Plasma Thermocouple.* H. W. LEWIS AND J. R. REITZ, *Los Alamos Scientific Laboratory.*—The efficiency of a thermionic converter containing cesium ions is calculated for the regime in which the plasma density is sufficiently high that the random current density, $nev/4$, is large compared to the actual current density. Under these circumstances positive space-charge barriers are set up at the cathode and anode, and the plasma region is many free paths in length. The output voltage V_L is determined for various currents by a consistent solution of the electrical and thermal conduction problems. The efficiency of the over-all circuit is

$$\eta = \frac{(V_L - IR_0)}{V_L + W_a + 2(k/e)T_a + (P_r + P_l)/I},$$

where W_a is the work function of the anode, T_a the temperature of the electron gas in contact with the anode, P_r the radiation loss through the thermocouple, R_0 and P_l the resistance and power loss, respectively, of the lead wire which completes the circuit. Efficiencies up to 32% are obtained for a typical thermocouple circuit.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Q9. (Abstract withdrawn.)

Q10. (Abstract withdrawn.)

Q11. Isomorphism in a New Aspect. N. EFREMOV, *600 West 142 Street, New York City.*—It is generally believed that isomorphous substitutions in crystals depend on two factors—the magnitude of ions and the type of crystalline lattice. But there is a third physical factor which might be called "the factor of achievement simple multiple relations between the masses of positively charged ions in crystalline lattice." It reflects the tendency of natural crystallization processes to achieve simple multiple relations between the mass (sum of atomic weights) of metals and the mass (atomic weight) of silicon in the composition of crystalline lattices of silicates. Therefore the chemical formulas of very abundant silicates such as rockforming magnesia-silicates (where Mg·· is partly substituted by Fe··) or alumosilicates—plagioclases (where Na·Si···· is partly substituted by Ca··Al···) the relation between the mass of metals and that of silicon approach or equal the relations between simple small numbers such as 1:1, 3:2, 2:1, etc. It is important to note that these simple multiple relations (e.g. 3:2) between the mass of metals and that of silicon are also found in some artificial minerals and particularly in silicates synthesized by Morey and Bowen.

Artificial silicates	Relations of atomic weights
$2Na_2O \cdot CaO \cdot 3SiO_2$	$(2Na_2+Ca):3Si=3.10:2$
$Na_2O \cdot 2CaO \cdot 3SiO_2$	$(Na_2+2Ca):3Si=2.98:2$

SATURDAY MORNING AT 9:30

Tomlinson Hall

(J. C. BOWMAN presiding)

Invited Paper

R1. Relation between Energy Band Structure and the Properties of Graphite. J. W. MCCLURE, *National Carbon Company.* (30 min.)

Semiconductors III

R2. Low-Resistance Organic Semiconductor. J. KOMMANDEUR AND FRANCES R. HALL, *Union Carbide Corporation* (introduced by L. S. Singer).—Addition of iodine to the aromatic hydrocarbon pyrene results in a material of a much lower resistivity than either one of the components by itself. The phase diagram of pyrene and iodine shows the existence of a metastable complex of composition 2 Py I_2, as well as a stable complex of composition Py 2 I_2. The latter material can also be prepared from solutions of the constituent components; pressed pellets have a specific resistivity of 75 Ω cm at room temperature. From the temperature dependence we find that the activation energy for conduction is about 0.11 ev. A complex prepared of another aromatic hydrocarbon perylene, and iodine, with the formula 2 Per 3 I_2 has a specific resistivity of 8 Ω cm at room temperature with an activation energy of 0.016 ev. Single crystals of this material show the same general behavior as the pressed pellets. Since a Hall effect was not observable in either of these substances, an upper limit for the mobility of 0.01 $cm^2\ v^{-1}\ sec^{-1}$ was inferred. The carrier densities, therefore, must be at least 7×10^{18} cm^{-3} and 8×10^{19} cm^{-3} for the pyrene and perylene complexes, respectively.

R3. Electron Spin Resonance in Some Organic Semiconductors. L. S. SINGER AND J. KOMMANDEUR, *National Carbon Company and Union Carbide Corporation.*—Electron spin resonance measurements have been made on organic semiconducting complexes of pyrene and perylene with iodine. At room temperature, the spin concentration in the pyrene-iodine complex is about 10^{19} g^{-1}. The temperature dependence of the spin concentration is exponential with an activation energy close to that found for the electronic conduction.[1] Furthermore, there is no anisotropy of the spin resonance in single crystals, and the spin-lattice relaxation time T_1 approximately equals the inverse line width T_2. These observations suggest that the spin resonance is due to charge carriers. At low temperatures we find that the spin concentration becomes independent of temperature, T_1 becomes much larger than T_2, and the resonance of single crystals becomes anisotropic; these results indicate that some type of trapped spin is present.

[1] J. Kommandeur and Frances R. Hall, Bull. Am. Phys. Soc. Ser. II, **4**, 421 (1959), preceding abstract.

R4. Preparation of Semiconductor and Insulator Films by Low-Pressure Pyrolysis.* E. H. TOMPKINS, R. H. BRAGG, AND J. W. BUTTREY, *Armour Research Foundation.*—Films of cubic SiC, amorphous B, and amorphous SiO_2 have been prepared by the pyrolysis of volatile metal-organic compounds at pressures of a few mm. The technique is being extended to CdTe, InSb, and BP. The success of the method depends strongly on the stability of the metal-organics selected and the geometry of the pyrolysis chamber. Temperatures of pyrolysis have not proven critical, but they must be high enough to prevent the deposition of volatile side products. The general method, its advantages, and recent optical and electrical data on films prepared will be presented.

* This research is sponsored by the Wright Air Development Center.

R5. Oscillistor—A New Type of Semiconductor Oscillator. R. D. LARRABEE AND M. C. STEELE, *RCA Laboratories.*—Current oscillations have been observed in an electron-hole plasma produced within a semiconductor. The plasma is produced by a constant voltage applied to the semiconductor

specimen through suitable injecting contacts. When the specimen is immersed into a constant magnetic field, current oscillations are detected across a series load resistance. These oscillations have been observed both in *N*- and *P*-type germanium at room temperature and in the following materials at 78°K: *N*- and *P*-type Ge, *P*-type Si, and *N*- and *P*-type InSb. Oscillation frequencies in germanium ranging from about 10 kc to over 50 mc have been observed. This device has tentatively been named the Oscillistor to suggest a semiconductor device capable of producing oscillations. The experiments indicate that the oscillations are due to the influence of the magnetic field in producing an interaction of the bulk plasma of electrons and holes with the exposed surface areas of the specimen. It is believed that this is a new phenomenon to semiconductors and that it may find many practical applications. The present observations are similar to those reported by Ivanov and Ryvkin[1] but they apparently were not cognizant of the necessity of having a comparatively high density plasma of electrons and holes in order to see the effect.

[1] I. L. Ivanov and S. M. Ryvkin, Soviet Phys.—Tech. Phys. **3**, 722 (1958).

R6. Negative Resistance (NR). Diode and Microwave Switching.* JENNY E. ROSENTHAL, *Bramley Consultants.*—Narrow junction and avalanche injection structures[1] exhibiting NR are compared. Esaki observed NR in narrow junctions ~150 A at forward voltages ~0.3 v. NR is also observed at higher voltages in wafers, e.g., almost intrinsic *n*-type layer between a metallic or *p*-type layer and a heavily doped *n*-bead, 50 μ apart, exhibiting avalanche injection. At high current densities with field high enough (10^5 v/cm) to generate carriers copiously, the space charge of majority carriers originated by avalanche injection concentrates the potential difference in a sheath near the negative electrode. The thickness of this sheath fluctuates with potential difference much more rapidly than the average electric field across the diode, creating NR conditions. Current density calculations indicate that this sheath is reduced to 6 μ at 90 v, i.e., the average electric field is 1.5×10^5 v/cm compared to 2×10^5 for narrow junctions. This agreement indicates significant similarity in carrier generation in the two structures. The avalanche injection diode is suitable for bistable operation or switching at kMc frequencies.

* Under contract to Avion Division, ACF Industries.
[1] Proc. Solid State Symposium, Brooklyn Polytech. Inst. **7**, 289 (1957).

R7. Room Temperature Semiconductor Particle Spectrometer. J. M. MCKENZIE AND D. A. BROMLEY, *Chalk River Laboratories.*—Gold silicon surface junctions as particle spectrometers have been found to give satisfactory resolution when operated at room temperature, in contrast to gold-germanium junctions[1] which operate satisfactorily only at a low temperature. This is not unexpected since silicon has a much larger energy gap than germanium (1.12 ev to 0.7 ev). A typical gold silicon junction with 4 v reverse bias shows a pulse height proportional to particle energy for alpha particles up to 3.5 Mev and for protons up to 0.8 Mev. The energy resolution of a typical 2×2 mm unit for 3.3 Mev alpha particles is 6%; the pulse rise time 40 mμ. A measurement of the energy required to produce an electron hole pair (3.60 ±0.15 ev) is in agreement with the previously reported value.[2] Phosphorus diffused *p-n* junctions have also been investigated and show comparable resolution. The application of these semiconductors for the detection of neutrons will be discussed.

[1] J. M. McKenzie and D. A. Bromley, Phys. Rev. Letters **2**, 303 (1959); International Convention on Transistors and Semiconductor Devices, Spec. Suppl., Proc. I.E.E. (London) Pt. B (May, 1959).
[2] K. C. McKay and K. B. McAfee, Phys. Rev. **91**, 1082 (1953).

R8. Free Carrier Absorption in the III-V Compound Semiconductors. S. VISVANATHAN, *Philco Corporation* (introduced by J. F. Walsh).—The longitudinal polar modes of vibration in the III-V compound semiconductors play an important part in determining their transport properties such as mobility, etc. One would expect them to be important in estimating the free carrier absorption in these semiconductors. A quantum mechanical calculation of the free carrier absorption arising from the polar modes has been made and gives an absorption coefficient varying as $\lambda^{3.5}$ and such behavior has been reported experimentally in InP[1] and GaP.[2] The calculated values of the absorption coefficient in InP are in fair agreement with experiment. The influence of this free carrier absorption on the Rest-Strahl reflection spectra of these compounds will be discussed.

[1] R. Newman, Phys. Rev. **111**, 1518 (1958).
[2] W. G. Spitzer (private communication).

R9. Electron Scattering in High Magnetic Field. ARNOLD H. KAHN, *National Bureau of Standards.*—Electrical conductivity in a strong magnetic field is calculated for the case of impurity scattering. Delta functions are used for the impurity potentials. An exact solution to the scattering problem is used, rather than approximation by first order time dependent perturbation theory. As a result, transition probabilities for an electron at the bottom of a Landau level vanish, rather than diverge. The transverse conductivity is finite without the use of a cutoff. Expressions are given for the longitudinal and transverse conductivities in the oscillatory range, and in the quantum limit range for degenerate and nondegenerate statistics. The results for the oscillatory range agree with those of Zilberman[1] and Argyres.[2]

[1] G. E. Zilberman, Zhur. Exptl. i Teoret. Fiz. **29**, 762 (1955); Soviet Phys. JETP **2**, 650 (1956).
[2] P. N. Argyres, J. Phys. Chem. Solids **4**, 19 (1958).

R10. Theory of Ambipolar Diffusion in a Semiconductor Photodiode at Low Temperatures. J. W. HORTON AND A. G. BLACHMAN, *IBM Watson Laboratory at Columbia University.*—A phenomenological theory is presented to interpret measurements of the saturated photocurrent in a germanium *PN* junction photodiode whose temperature is 4.2°K. Electrons and holes produced by a spot of light on one broad face of a thin slab of semiconductor material diffuse toward a reverse-biased junction near the opposite face and coplanar with it. Electrodes are attached to the broad faces. The charge transport problem is characterized by excessive hole-electron recombination and by the presence of an electric field arising from the ambipolar diffusion and the boundary condition imposed by the junction. To take these effects adequately into account, three nonlinear, simultaneous differential equations must be solved. Simple rigorous solutions are obtained assuming hole and electron densities equal, and a recombination rate proportional to either the first or the second power of the charge densities. Because the former case seems experimentally realizable, analysis has also been made of the photocurrent in response to a small, additional illumination of sinusoidally varying intensity. The steady state and time dependent theories then show how both the hole and electron mobilities and the recombination constant may be measured for a single piece of bulk material. Preliminary measurements will be reported of the recombination at 4.2°K in 0.03 ohm-cm indium doped germanium.

R11. Oscillatory Charge Distribution near a Defect.* S. MACHLUP AND H. OGATA, *Western Reserve University.*—It has been suggested[1] that the free-electron screening of a point imperfection (impurity or vacancy) in a (cold) metal is not complete, but that the electron charge density in the vicinity includes an oscillatory term whose amplitude falls off as the inverse cube of the distance, of period π/k_F (where

k_F is the wave number of an electron at the Fermi level). Noninteracting electrons in any centrally symmetric potential of finite range have density

$$\rho(r)=\rho_0+(1/\pi^2)\ \Sigma_l\,(2l+1)_0\int^{k_F}[\sin^2(kr+\eta)-\sin^2(kr)]k^2dk,$$

where $\eta=\eta_l(k)$ is the phase shift of the lth partial wave. At large distances where the spherical Bessel functions may be approximated by their asymptotic forms $\rho(r)$ does oscillate as suggested. The effect can be attributed to electrons within a wave number interval $\eta_l(k_F)/r$ below k_F, and would disappear at high enough temperatures.

* Supported by the U. S. Atomic Energy Commission.
[1] Harvey Brooks (informal communication).

SATURDAY MORNING AT 10:00

Physics 301

(M. E. MERCHANT presiding)

Invited Papers

S1. Recent Work on Liquid and Solid Helium 3. J. G. DAUNT, *Ohio State University.* (30 min.)

S2. Specific Heat Anomalies in Metals below 1°K. C. V. HEER, *Ohio State University.* (30 min.)

S3. Recent Observations of Intense Solar Cosmic Rays. PHYLLIS S. FREIER, *University of Minnesota.* (30 min.)

Post-Deadline Papers, If Any

SATURDAY AFTERNOON AT 1:30

Strosacker Auditorium

(FREDERICK REINES presiding)

Invited Papers

U1. Recent Experiments on the g Factor of the Electron. H. R. CRANE, *University of Michigan.* (30 min.)

U2. Magnetic Moment of the Muon. SHELDON PENMAN, *Columbia University.* (30 min.)

U3. Nuclear Resonance with Short-Lived Beta Emitters Produced by Neutron Capture. DONALD CONNOR, *Argonne National Laboratory.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Bingham 103

(STEFAN MACHLUP presiding)

Invited Paper

V1. Structural and Magnetic Properties of Thin Films. R. W. HOFFMAN, *Case Institute of Technology.* (30 min.)

Magnetism and Ferroelectricity

V2. Magnetic Field Dependence of Ultrasonic Attenuation in Aluminum. B. W. ROBERTS, *General Electric Research Laboratory.*—Aluminum single crystals prepared by twelve-pass zone refining[1] and having a resistivity ratio of 8100, as measured directly on the specimen by an eddy-current technique,[2] have been studied by the ultrasonic pulse method.[3] Measurements have been made at 4.2°K in magnetic fields, H, up to 9200 gauss. A single unexplained maximum in the attenuation is observed for longitudinal pulse propagation at 49 Mc/sec along [111] when H lies along [$\bar{1}$10] and other directions normal to [111]. Longitudinal pulse propagation along [110] yields an oscillatory attenuation when H is parallel to [1$\bar{1}$1], while pronounced oscillations are not seen when H is parallel to [001] or [1$\bar{1}$0]. Short period oscillations of small amplitude are observed at large H and suggest de Haas-van Alphen oscillations as reported in Bi by Reneker. Comparison with current theories of the aluminum Fermi surface will be made.[4]

[1] Prepared by K. T. Aust and J. E. Hilliard of this laboratory.
[2] Bean, DeBlois, and Nesbitt, J. Appl. Phys. **30** (to be published).
[3] R. W. Morse, *Progress in Cryogenics. I* (Heywood and Company, Ltd., London, 1959), p. 221.
[4] V. Heine, Proc. Roy. Soc. (London) **A240**, 340 (1957); W. A. Harrison, Phys. Rev. (to be published).

V3. Spin Wave Calculations for Canted Ferrimagnetics.* HENRY UNRUH,† *Case Institute of Technology.*—The spin wave dispersion law for simple cubic and body centered cubic crystals of ferrimagnetics is derived. The result allows arbitrary g factors, spins, externally applied fields, and anisotropy fields if their interaction energy with the spins is in the cosine dependent form. If the interaction energy is in the cosine squared dependent form, then the externally applied field must lie in the plane determined by the anisotropy fields acting on the two sublattices. Values for the integrals needed to calculate the spin wave contribution to the specific heat and the magnetization have been obtained by means of a computing machine for a wide range of crystal constants and externally applied fields.

* Supported by Office of Naval Research and the Research Corporation through a Frederick Gardner Cottrell grant.
† Now at Colorado State University.

V4. Mechanism of Magnetization Reversal in Ticonal G. B. SCHECHTER AND S. SHTRIKMAN, *The Weizmann Institute of Science, Rehovoth* (introduced by W. F. Brown).—Magnetic measurements were carried out on a Ticonal G disk in an attempt to clarify the mechanism of magnetization reversal in this anisotropic alloy. These measurements, which were made using a vibrating sample magnetometer,[1] showed that the coercive force for the parallel component of the magnetization decreased, while that for the perpendicular one increased, with angle to the magnetic axis. These results, together with the value 1.0 obtained for the rotational hysteresis integral,[2] support a model of plate like elements[3] in which the magnetization reverses by coherent rotation. It should also be noted that the measured remanence curves were found to agree with theoretical relations previously derived,[4] showing that these elements are uniaxial.

[1] S. Foner, Rev. Sci. Instr. **30**, 548 (1959).
[2] This value is in agreement with that obtained for the similar alloy, Alnico V, by I. S. Jacobs, Bull. Am. Phys. Soc. Ser. II, **2**, 117 (1957).
[3] E. A. Nesbitt and H. J. Williams, J. Appl. Phys. **26**, 1217 (1955).
[4] Frei, Shtrikman, and Treves, J. Appl. Phys. **30**, 443 (1959).

V5. Nuclear Quadrupole Resonance in an Antiferromagnet. J. C. BURGIEL,* *Bell Telephone Laboratories and M.I.T.*, AND V. JACCARINO AND A. L. SCHAWLOW, *Bell Telephone Laboratories.*—NQR techniques have been applied to studies of the magnetic interactions in bromates and iodates of certain $3d$ transition metal ions. In particular, for $Ni(IO_3)_2 \cdot 2H_2O$ there is an abrupt disappearance of the $I^{127}(\pm\frac{5}{2} \leftrightarrow \pm\frac{3}{2})$ transition at 3.08°K; at lower temperatures there is a large, temperature dependent splitting. This behavior is attributed to the combined effects of an antiferromagnetic ordering of the Ni^{++} electron spins and a strong hfs interaction of the nonlocalized Ni^{++} spin magnetization with the I^{127} nuclear magnetic moment.[1] From measurements of the quadrupole frequencies in zero external field for the transitions $(\pm\frac{5}{2} \leftrightarrow \pm\frac{3}{2}$, 296.6 Mc) and $(\pm\frac{3}{2} \leftrightarrow \pm\frac{1}{2}$, 148.8 Mc) above and of the splittings below the antiferromagnetic transition temperature, the asymmetry of the electric field gradient (EFG) tensor, the relative orientation of the principal axes of the EFG tensor and the hfs field, and the temperature dependence of the sublattice magnetization have been determined. Qualitative measurements at 1.3°K indicate that $T_2^{127} \sim 10^{-6}$ sec and $T_1^{127} \ll 100$ sec, which indicates large electronic-nuclear magnetic interactions in the ordered state. Measurements of the susceptibility and the Curie-Weiss temperature are consistent with these conclusions.

* This work performed in partial fulfillment of the requirements for the degree of Master of Science.
[1] V. Jaccarino and R. G. Shulman, Phys. Rev. **107**, 1196 (1957).

V6. Low-Frequency Electrical Characteristics of Lead Titanate Zirconate Ceramics.* ROBERT GERSON, *Clevite Corporation.*—The characteristics of an unmodified lead titanate zirconate composition and of a similar composition containing a niobium substituent which increases the resistivity by several orders of magnitude were determined between room temperature and 140°C at frequencies between 0.1 cps and 10 cps. A measured increase in dielectric constant and dissipation factor at low frequency and high temperature was interpreted as an anomalous conduction phenomenon, rather than as an effect because of ferroelectric polarization. It was found that the resistivity calculated from dissipation factor measurements varied inversely as a power of the frequency lying between zero and one, the power being a function of the temperature and the material. Over the frequency and temperature range studied the relationship between the real and the imaginary components of the dielectric constant was found to be linear. The data for unpoled ceramic and for material which had been poled to a maximum in piezoelectric activity were quite similar.

* Supported by the Office of Naval Research.

V7. Anisotropic Thermal Expansion and Pyroelectric Effect in Poled Ferroelectric Ceramics.* W. R. COOK, JR., HANS JAFFE, AND D. A. BERLINCOURT, *Clevite Corporation.*—The anisotropy of poled ferroelectric ceramics is marked in thermal expansion. For barium titanate, thermal expansion is about half as large in the poling direction as perpendicular thereto. In a typical lead titanate zirconate ceramic a contraction of 7.2×10^{-6}/°C takes place in the poling direction and an expansion of 5.3×10^{-6}/°C perpendicular thereto when the sample is heated for the first time after poling. Somewhat smaller anisotropy is observed on repeated cycling between room temperature and temperatures below the Curie point. The expansion of the unpoled ceramic is 2.0×10^{-6}/°C. It has been pointed out[1] that the sign of the secondary pyroelectric effect calculated from thermal expansion of barium titanate ceramics is opposite to the measured total pyroelectric effect. In poled lead titanate zirconate the secondary and total pyroelectric effects have the same sign, and this becomes true also for poled barium titanate if only the anisotropic part of thermal expansion is considered. There remains, however, a substantial primary pyroelectric effect, especially on the first heating cycle, which can be ascribed to 180° domain switching. The pyroelectric effect in the individual unswitched domains is known to be essentially secondary.

* Research supported by the Sandia Corporation.
[1] Perls, Diesel, and Dobrov, J. Appl. Phys. **29**, 1297 (1958).

V8. High-Temperature Discharges in Ferroelectric Ceramics.* JOHN W. NORTHRIP, *Sandia Corporation.*—Ceramic disks of barium titanate and lead zirconate titanate, when heated above 100°C, exhibit current discharges which cannot be attributed to the ferroelectric polarization of the material. These discharges are largest in the temperature interval 300°–600°C and appear to depend on the electrode material and its method of application. We have obtained discharges of several millicoulombs at voltages up to $\frac{1}{2}$ v from a ceramic disk $\frac{1}{2}$ in. in diameter and 30 mils thick having a silver electrode and an indium counterelectrode. Although thermoelectric, pyroelectric and electret effects are observed in these samples, these phenomena contribute only a very small portion of the total discharge. At constant temperature the discharge decays with time as the sum of two exponentials, falling to half maximum in periods of the order of one hr. An increase of temperature causes an increase of the decay rate while temperature cycling produces a voltage cycling superimposed on the decay. These findings support an explanation of the effect in terms of secondary cell activity between the metallic electrodes and mobile oxygen vacancies in the titanate lattice.

* Work performed under U. S. Atomic Energy Commission contract.

V9. Width of Electromagnetic Shock Waves in a Nonlinear Dielectric. R. LANDAUER, *IBM, Poughkeepsie,* AND L. H.

THOMAS, *IBM, Watson Laboratory.*—A TEM wave propagating through a nonlinear dielectric will be subject to distortion, since different portions of the wave will travel with differing velocities, $c/(\mu\epsilon)^{\frac{1}{2}}$. This distortion can result in the formation of shock waves. The detailed structure of the shock wave is determined by the high frequency dispersion characteristics of the system. For ferroelectrics, just above the transition temperature at which the spontaneous polarization disappears, it is possible that the main source of dispersion resides in the dielectric itself and is fixed by the behavior of the lowest frequency optical mode, whose relation to ferroelectricity has been explained by Anderson.[1] We have studied the detailed structure of the shock wave, assuming a reasonable dispersion law for the ferroelectric, allowing for both damping forces and inertial forces on the part of the charges which move to establish the induced polarization. The entropy changes associated with the irreversible shock transition lead to negligible departures from the adiabatic ferroelectric characteristics.

[1] P. W. Anderson, Preprint of paper presented at the Moscow Conference on Dielectrics, December 1958.

V10. Effects of Gamma Radiation on the Properties of Rochelle Salt.* HELMUT H. A. KRUEGER, *Clevite Corporation.*—Elastic and dielectric properties of Rochelle salt X-cut plates were studied after exposure to Co^{60} radiation from 10^4 to 3×10^7 roentgens. The elastic stiffness coefficient c_{44}^D remains unchanged to 3×10^6 roentgens with softening at higher dosages. Curves of stiffness at constant field c_{44}^E and dielectric constant show initial sharpening of the Curie points at 10^4 and 10^5 roentgens followed by a broadening and then merging which indicates disappearance of the ferroelectric phase. Between Curie points the mechanical Q rises as the ferroelectric phase is diminished by radiation, not dropping until 3×10^7 roentgens at which level the material is lossy because of the many lattice disruptions. The slow rise in dielectric dissipation at the lower Curie point becomes a sharp peak after 10^4 and 10^5 roentgens. The sharp peak in dissipation at the upper Curie point is diminished in intensity for this dosage. X-ray double crystal rocking curves taken above the Curie range confirm the elastic and dielectric results: the width of the measured line decreases up to 10^5 roentgens and broadens thereafter. There is no measurable change in lattice constants.

* Work supported by the U. S. Atomic Energy Commission and Clevite Corporation.

SATURDAY AFTERNOON AT 1:30

Physics 301

(L. L. FOLDY presiding)

Invited Papers

W1. Long-Lived Metastable States of the Nitrogen Atom (with demonstrations). CARL KENTY *General Electric Company, Nela Park.* (45 min.)

W2. Low-Energy Properties of Nuclei with a Pairing and a Long-Range Interaction. L. S. KISSLINGER, *Western Reserve University.* (30 min.)

W3. General Relativity in the State of a Star. J. W. WEINBERG, *Western Reserve University.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Physics 316

(JOHN NIXON presiding)

Radioactive Nuclei

X1. β^-,γ Discrimination for Low Level Counting.* FREDERICK REINES, *Case Institute of Technology.*—The predominant source of background in many low-level beta counting experiments is gamma rays. These gamma rays originate from natural emitters such as K^{40} and the radium family. In order to distinguish between unwanted gamma-ray signals and the interesting ($\lesssim$1 Mev) betas we are currently investigating an approach which takes advantage of the fact that the energy loss which occurs in materials of low atomic number is primarily due to multiple Compton collisions. In a liquid scintillator, such as toluene for example, these collisions are separated in space (λ compton $\sim$10 cm) whereas the beta particle loses its energy in smaller distances ($\sim$0.5 cm). The detection scheme under study discriminates between β^- and γ events by taking advantage of this difference in spatial extent. A region small compared with the compton m.f.p but comparable with the beta range is imbedded in a region which is several compton m.f.p. in extent. The signals received from these two regions are distinguished by different emission spectra produced by the proper selection of scintillators, so enabling the use of coincidence techniques to discriminate between the two types of radiation.

* Supported by the Research Corporation and the Alfred P. Sloan Foundation.

X2. Nuclear Polarization of Co^{55}.* RUDOLF W. BAUER AND MARTIN DEUTSCH, *MIT.*—The angular distribution of the gamma rays emitted from 18-hr Co^{55}, polarized at low temperatures in cerium-magnesium-nitrate crystals, has been measured. The amplitude mixing ratios $\delta(E2/M1)$ of admixed

gamma rays in Fe^{55} have been determined. From a simultaneous measurement of the angular distribution of the gamma rays from polarized Co^{55} and Co^{55}, grown into the same crystals, the ratio of the nuclear g values of (g_{58}/g_{55}) has been determined. With a spin of $\frac{7}{2}$ for Co^{55} and a spin sequence of $\frac{7}{2} \rightarrow \frac{5}{2} \rightarrow \frac{3}{2}$ in the main decay in Fe^{55}, we find for the 0.935-Mev gamma ray a δ of $+0.36 \pm 0.11$ or $> +8$, and for the magnetic moment of Co^{55} 5.35 ± 0.35 n.m., if the 1.03 Mev beta branch is predominantly a G. T. transition, 4.6 ± 0.4 n.m., if pure Fermi. A spin sequence $\frac{5}{2} \rightarrow \frac{7}{2} \rightarrow \frac{3}{2}$ in Fe^{55} is not excluded by our measurements; this would give for the 1.41-Mev gamma ray a δ of $+0.8 \pm 0.4$ or $+3.0 \pm 2.0$ and for $\mu_{55} = 4.1 \pm 0.9$. The errors include the unknown amount of mixture in the preceding gamma and beta transitions.

* This work is supported in part through the U. S. Atomic Energy Commission, by funds provided by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Air Force Office of Scientific Research.

X3. Beta-Gamma Directional Correlation in Rb^{86}. J. H. HAMILTON,* B. G. PETTERSSON, AND J. M. HOLLANDER,† *University of Uppsala.*—The directional correlation of the once forbidden 710-kev beta group with the 1.08-Mev gamma ray in Rb^{86} has been measured previously.[1] Kotani points out[2] in his discussion of the Rb^{86} decay how a measurement of the directional correlation as a function of beta energy over a wider range of energy would be useful in further analysis. The Rb^{86} β-γ directional correlation has been measured again as a function of beta energy over a wider range of energy from 105 to 620 kev and with improved techniques. A magnetic lens spectrometer with 6.5% momentum resolution was used as the beta analyzer. The maximum correlation of $A = 0.38$ at 620 kev [where $A = [N(\pi) - N(\pi/2)]/N(\pi/2)]$ is higher than previously reported[1] (i.e., $\simeq 0.22$ at 600 kev[1]). A theoretical analysis of this result will be made.

* National Science Foundation Postdoctoral Fellow on leave from Vanderbilt University.
† Guggenheim Fellow on leave from the Lawrence Radiation Laboratory, University of California.
[1] D. T. Stevenson and M. Deutsch Phys. Rev. **83**, 1202 (1951).
[2] T. Kotani, Phys. Rev. **114**, 795 (1959).

X4. Gamma Radiation from 8-Day Ag^{106}. W. L. BENDEL, *Nucleonics Division, U. S. Naval Research Laboratory.*—The long-lived isomer of Ag^{106} was produced by bombarding metallic silver with 18-Mev bremsstrahlung from the NRL betatron. Spectra of single gamma rays, of double and triple coincidences, and of summation pulses have been examined with NaI(Tl) crystals. When the source was placed between two 5-in. diam by 4-in. long crystals, summation pulses of 2.79 ± 0.02 Mev were observed. An "average" cascade of about 3.7 gamma rays was indicated by the dependence of summation-peak intensity on solid angle. Coincidence data show cascades consisting of 0.72-, 1.54-, and 0.51-Mev and of 1.2-, 1.04-, and 0.51-Mev gamma radiation. Spectra of individual quanta exhibit peaks and intensities in fair agreement with values reported for this activity[1,2] and for the 130-min isomer[3] of Rh^{106}. The data indicate that the 8-day isomer of Ag^{106} decays (by electron capture) largely to a level at 2.78 Mev in Pd^{106}. A decay scheme will be presented.

[1] D. E. Alburger and B. J. Toppel, Phys. Rev. **100**, 1357 (1955).
[2] R. L. Robinson and F. K. McGowan, Bull. Am. Phys. Soc. Ser. II, **4**, 279 (1959).
[3] S. Mayo and S. J. Nassiff, Publ. Comm. Nacl. Energia Atomica (Buenos Aires), Ser. Fis. 1, No. 12 (1957).

X5. Decay of Eu^{147} to Levels in Sm^{147}. C. F. SCHWERDTFEGER AND J. W. MIHELICH, *University of Notre Dame,** AND B. HARMATZ, *Oak Ridge National Laboratory.*†—The decay of Eu^{147} (24 days) has been studied with permanent magnet spectrographs and scintillation spectrometers. Transitions of 76 kev ($M1+30\%$ $E2$), 122 kev ($M1+5\%$ $E2$), 198 kev ($E2$), 600, 676, 800, 900, 976, and 1100 kev have been observed. Levels of 122, 198, -800, and -1100 kev in Sm^{147} have been established. Two weak positron branches with endpoint energies of 270 and 150 kev have been detected. The lower energy branch is in coincidence with the 122-kev transition. It is likely that the 270-kev branch proceeds to the ground state of Sm^{147} ($I = \frac{7}{2}-$) and that the energy available for decay of Eu^{147} is 1290 ± 20 kev.

* Supported by the U. S. Atomic Energy Commission.
† Operated for the U. S. Atomic Energy Commission by Union Carbide Nuclear Company.

X6. Internal Conversion Electrons Following Coulomb Excitation of Eu^{151}.* E. M. BERNSTEIN† AND R. GRAETZER, *University of Wisconsin.*—The internal conversion electrons emitted following Coulomb excitation of an enriched (92%) Eu^{151} target have been measured. The transitions observed and their K/L ratios are as follows: 110 kev; 175 kev, 4.5; 193 kev, 5.5; 282 kev, 3.6; 304 kev, 6.7. Except for the 175-kev transition which was not observed before the results are in reasonable agreement with a previous experiment.[1] The yield of the 175-kev transition as a function of bombarding energy indicates that it is a cascade from a level of about 500 kev. From its energy and K/L ratio the 175-kev transition may be the $M2$ transition seen in Eu^{151} following electron capture of Gd^{151}. Absolute transition probabilities have been measured and will be given along with a possible decay scheme for Eu^{151}.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† Now at Institute for Theoretical Physics, Copenhagen.
[1] C. M. Class and U. Meyer-Berkhout, Nuclear Phys. **3**, 656 (1957).

X7. Shape of the Beta Spectrum of Eu^{152}.* L. M. LANGER, D. R. SMITH, AND M. P. KLEIN, *Indiana University.*—Previous measurements on the shape of the highest energy beta group on the decay of 13-year Eu^{152} have suggested that the spectrum has an "unique" shape[1,2] or an "allowed" shape.[3] Measurements made with a strong, relatively thin source in a high resolution spectrometer permit a definitive interpretation of the spectrum shape in spite of the presence of interfering internal conversion lines. The shape is found to be neither "allowed" nor "unique." For energies above $W = 3.2 m_0c^2$, the distribution is best fitted by a shape factor $(W_0 - W)^2 + 0.791(W^2 - 1) + 5 \pm 2$, with $W_0 = 3.902 m_0c^2$ corresponding to an endpoint of 1.483 ± 0.007 Mev. The shape is consistent with what one might expect for a once forbidden $3-$ to $2+$ transition with an abnormally high comparative half life.

* Supported by the Office of Naval Research.
[1] Bhattacherjee, Nainan, Raman, and Sahai, Nuovo cimento **7**, 501 (1958).
[2] Cork, Brice, Helmer, and Sarason, Phys. Rev. **107**, 1621 (1957).
[3] Alburger, Ofer, and Goldhaber, Phys. Rev. **112**, 1998 (1958).

X8. Nuclear Resonance Fluorescence with the 105-kev E1 Transition of Gd^{155} Using an Ultracentrifuge.* B. I. DEUTCH, F. R. METZGER, AND F. J. WILHELM, *Bartol Research Foundation.*—1.7-yr Eu^{155} was produced from a pile irradiation of enriched Sm^{154} via the $Sm^{154}(n,\gamma)Sm^{155}$ reaction. The Eu^{155} formed from the 23-minute decay of Sm^{155} was separated by means of ion exchange resins. By using a 5-in. Al rotor in an air-driven ultracentrifuge, the Eu^{155} source was rotated in a vacuum clockwise at a velocity of 230 m/sec and counterclockwise at a velocity of 294 m/sec. In addition, measurements were taken at zero velocity. For the geometry used, the clockwise rotation gives rise to a Doppler shift of the emission line which compensates for the recoil energy losses. The counter clockwise rotation eliminates the overlap of the emission line with the absorption line. Nuclear resonance fluorescence from the 105-kev level of Gd^{155} was measured in a scattering experiment using Gd_2O_3 as the scatterer and Sm_2O_3 as the comparison scatterer. From the magnitude of the resonance effect, assuming a total conversion coefficient of $\alpha_T = 0.26$, a mean life $\tau_\gamma = 6.0_{-2}^{+6} \times 10^{-10}$ sec was calculated for this hindered $E1$ transition.

* Supported by a grant from the National Science Foundation.

X9. Decay of Dy^{166} (80.2 hr).* R. G. HELMER AND S. B. BURSON, *Argonne National Laboratory.*—The radioactive isotope $_{66}Dy^{166}$ was produced by double neutron capture in dysprosium oxide enriched in Dy^{164}. Irradiation facilities of both the CP-5 reactor at Argonne and the Materials Testing Reactor at Arco, Idaho, were used for activations. For some of the experiments, the Dy^{166} activity was separated from the daughter activity, Ho^{166}, by use of an ion-exchange column. Internal-conversion-electron groups were observed photographically in a 180° uniform-field beta spectrograph; these indicated gamma-ray transitions of 82.5, 54.2, and 28 kev. Scintillation studies, made with a 256-channel coincidence scintillation spectrometer, revealed the existence of other gamma-ray transitions of 427, 368, 346, and 286 kev. The beta spectrum above 150 ev consists of a single component whose end-point energy is 408±5 kev. A level scheme will be presented which has excited states in Ho^{166} at 427, 368, 82, and 28 (or 54) kev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

X10. Transverse Polarization of Conversion Electrons Following the Beta Decay of Hg^{203}.* J. E. ALBERGHINI† AND R. M. STEFFEN, *Purdue University.*—As a result of the nonconservation of parity in weak interactions, it has been shown that internally converted electrons following a beta transition possess appreciable longitudinal and transverse polarization,[1] the latter being in the plane defined by the momentum vectors of the beta particle and the conversion electron. As a measure of the transverse polarization $P_\perp$ of the Hg^{203} conversion electrons, the left-right asymmetry in a Mott scattering process from a thin gold foil (180 $\mu g/cm^2$) was determined. Hg^{203} was chosen because of its relatively large conversion coefficient; in addition, the K-shell conversion peak is well separated from the continuous beta spectrum. Corrected for background and spurious instrumental asymmetries, the Mott asymmetry was found to be -0.041 ± 0.016, yielding a value of $P_\perp$ of $+0.11\pm0.04$. The beta transition in Hg^{203} is first-forbidden. Since Hg^{203} has an allowed shape and $\xi=\alpha Z/2R\simeq 15\gg 1$, the use of the ξ approximation[2] is appropriate. Within the frame work of this ξ approximation, the experimental result of $P_\perp$ gives strong support to the $\frac{3}{2}$-$\frac{3}{2}$-$\frac{1}{2}$ spin sequence.

* Supported by the U. S. Atomic Energy Commission.
† Sponsored by the Hughes Master of Science Fellowship Program.
[1] R. L. Becker and M. E. Rose, Phys. Rev. Letters 1, 116 (1958) and Nuovo cimento (to be published).
[2] T. Kotani and M. Ross, Phys. Rev. Letters 1, 140 (1958).

SATURDAY AFTERNOON AT 1:30

Tomlinson Hall

(J. W. MCCLURE presiding)

Solid-State Physics

Y1. Dielectric Loss from Combined Conduction and Diffusion.* ROBERT D. BARNARD AND SELBY M. SKINNER, *Case Institute of Technology.*—The dielectric loss resulting from the diffusion component of the combined conduction and diffusion, characteristic of nonmetallic conduction is calculated as a function of frequency, for a one-dimensional model of dielectric. By using the steady-state conduction-diffusion equation, and treating the applied field as a boundary perturbation, a Green's function is obtained, yielding a solution depending only upon combined diffusion and conduction, and not utilizing any specific dipole rotation or polarization mechanisms. The frequency dependence of loss is associated with the electrical parameters, and suitable experimental values of mobility and diffusion constant yield different frequency regions. The Cole-Cole plot is a close approximation to a semicircle, the quality of the approximation depending upon the rapidity of convergence of an associated infinite series. Experimentally observed deviations from a semicircle are justified by higher order terms. The equivalent electrical circuit is derived, and an expression is given for the average power per unit volume.

* With the support of the Office of Ordnance Research, U. S. Army.

Y2. Photoelectric Evidence for Valence Band Structure in Alkali Iodides. H. PHILIPP, E. TAFT, AND L. APKER, *General Electric Research Laboratory.*—Energy distributions of intrinsic external photoelectrons[1] from CsI, RbI, KI, and NaI have been measured in an extended range of photon energies. At $h\nu=11.3$ ev, the results are very unusual. In the case of CsI, for instance, only a small fraction of the photoelectrons emerge with kinetic energies below about 2 ev. A plausible, simple interpretation is that the valence band in this salt is roughly 3.5 ev wide. Since the top of this band, relative to the vacuum level, lies at about -6 ev,[1] the bottom would then lie at -9.5 ev. The energy range from -9.5 to -11.3 ev thus would contain no initial states from which photoelectrons could be excited. Accordingly, in a simple photoelectric process, no external photoelectrons would appear with energies below 1.8 ev. In these alkali halides, one would not expect strong inelastic electron-electron scattering to mask this simple effect for $h\nu<12$ ev. Reproducible structure also is visible in the energy distributions. The experiment thus gives information on the product of the valence band state density and a transition probability, somewhat as in the case of soft x-ray emission. Preliminary results show that the approach is interesting in the case of alkali chlorides and bromides at slightly higher photon energies.

[1] H. R. Philipp and E. A. Taft, J. Phys. Chem. Solids 1, 159 (1956); 3, 1 (1957).

Y3. Elastic Constants of RbBr, CsBr, RbI, and CsI Single Crystals. D. I. BOLEF AND M. MENES, *Westinghouse Research Laboratories.*—The elastic constants of single crystals of the rubidium and cesium bromides and iodides have been measured at room temperature using conventional pulse techniques and a high-frequency mechanical resonance technique. When end corrections are taken into account, the results of the two techniques agree to within the estimated probable errors. In units of 10^{11} dynes/cm, the measured values of the elastic constants are:

	C_{11}(%)	C_{44}(%)	C_{12}(%)
RbBr	3.17±0.8	0.388±0.8	0.42±10
CsBr	3.00±0.8	0.756±0.8	0.78±8
RbI	2.56±0.5	0.287±1	0.31±10
CsI	2.46±0.5	0.624±0.5	0.67±4

Y4. Elastic Constants of Ammonium Dihydrogen Phosphate (ADP) and the Laval Theory. HANS JAFFE, *Clevite Corporation.* Joel and Wooster[1] have shown that the Laval theory destroys

the identity $c_{44}=c_{55}$ which follows from the classical theory of elasticity for crystals of point group V_d to which ADP belongs. They find tentative experimental evidence for a difference of 8% between these constants in an earlier elasto-optic study.[2] In the course of 10 years this laboratory has measured resonance frequencies of about 100 plates which depend either on c_{44} or c_{55}. No distinction between these constants was made but no discrepancy was ever observed. The same is also true for an almost equal number of potassium dihydrogen phosphate plates. We have now cut two square plates perpendicular to the X axis and two square plates perpendicular to the Y axis of the same ADP crystal; the sides of the plates in each case are at 45° to the other axes. The fundamental contour resonance frequency constants which depend, respectively, on c_{44} and c_{55}, agree within the margin of error which is less than 0.1%. There is thus no experimental confirmation for the Laval theory in the elastic behavior of ADP.

[1] N. Joel and W. A. Wooster, Acta Cryst. **11**, 575 (1958).
[2] B. Zwicker, Helv. Phys. Acta **19**, 523 (1946).

Y5. Ultraviolet Transmission of Dihydrogen Phosphate and Arsenate Crystals. WARREN J. DESHOTELS, *Clevite Corporation.*—Ultraviolet transmission curves have been obtained for propagation parallel to the optic axis of ammonium and potassium dihydrogen arsenate and dihydrogen phosphate, and perpendicular to the optic axis of potassium dihydrogen arsenate. It was found that the absorption edges for ammonium and potassium dihydrogen arsenate occur at approximately 2180 A with a satellite absorption appearing at 2370 A. Ammonium dihydrogen phosphate is highly transparent to at least 2100 A in the ultraviolet while potassium dihydrogen phosphate appears to have an absorption edge somewhat below 2100 A with a weak satellite at 2200 A. Transmission data perpendicular to the optic axis of potassium dihydrogen arsenate are similar to that parallel to the axis, but satellite absorption is somewhat broader and its peak displaced slightly toward longer wavelength. Inasmuch as these crystals are transparent (50 to 80% transmission) to at least 2500 A, they may be used as electro-optic shutter elements in the near ultraviolet including the 2537 A mercury resonance line.

Y6. Resistance and Capacitance of, and Dielectric Absorption in Polystyrene Films.* JOHN J. SPOKAS, *Radio Corporation of America.*—The electrical characteristics of thin dielectric films have been studied by a method in which an electrical contact to the free surface of the film is effected with an electron beam. The specimens were prepared on a conducting substrate by the *in situ* electric discharge polymerization of styrene vapor[1] and ranged in thickness from 0.1 to 3.0 microns. The relaxation time of a potential, either positive or negative, applied across the film decreases from $>10^7$ sec at low electric fields to 5×10^5 sec for initial applied fields greater than 10^6 v/cm. The capacitance, not including volume charging effects, is independent of field intensity. Appreciable absorption currents are observed whose qualitative features can be understood in terms of conduction and trapping of electric charge in the interior of the material.

* Part of this work was performed under a contract with the U. S. Army Signal Corps, Fort Monmouth, New Jersey.
[1] Radiation Research Corporation, Film Dielectric Capacitors, First Quarterly Progress Report June 1, 1957, Signal Corps Contract ASTIA No. AD 148353. Unclassified.

Y7. Experimental Correlation of Charge Transfer and Mechanical Behavior in Frictional Stick-Slip between Plastics and Metals.* EDWARD L. KERN AND SELBY M. SKINNER, *Case Institute of Technology.*—Two of the following were measured simultaneously and individually without cross-effects: the horizontal and vertical components of force and the electrical potential on the slider. A chemical method was developed for obtaining uncharged polymer surfaces. Events of appreciable magnitude were observed primarily in a dry nitrogen atmosphere and at low traverse speeds. Magnitude of voltage curve is related to magnitude of horizontal force. Simultaneous changes in potential and horizontal force without changes in vertical force during the slip phase show correlation between electrical charge transfer and the stick-slip phenomenon. Results support the Bowden view of adhesion in stick-slip, and the Schnurmann view of charge-dependence of stick-slip. The presence of an initial charge reduces both the horizontal force component and the voltage transient.

* With the support of the Office of Ordnance Research, U. S. Army.

Y8. Hysteresis of Electric Charge Accompanying Deformation of Polymeric Materials.* SELBY M. SKINNER AND EDWARD L. KERN, *Case Institute of Technology.*—Different plastics were stressed flexurally, and charge behavior observed. Sign of charge developed on the side compressed is opposite to that on tension side. A phase lag is observed between deformation and charge buildup, and on release a nearly repetitively reproducible hysteresis loop results. Experimental results imply a piezoelectric type behavior of small magnitude, representing polarization throughout the material, or a strain-dependent surface charge. Sign of charge, its magnitude for a given deflection, area of loop, slope of mean line, and detailed appearance of the hysteresis loop are characteristic of type, composition and history of polymer sample, and rate of deformation. By rate-dependence, the relaxation time of the effect can be studied. This is a fourth hysteresis type additional to those described by Alfrey.[1] Analogously to known stress behavior in metals, charge decreases with time in a stationary deformed polymer; upon release, charge behavior is as if the original no-stress position had moved toward the position in which the polymer was held.

* With the support of the Manufacturing Chemists' Association, Inc.
[1] T. Alfrey, Jr., *Mechanical Behavior of High Polymers* (Interscience Publishers, Inc., New York, 1948), p. 200.

Y9. Photoconductivity in Natural Crystals of Stannic Oxide.* E. E. KOHNKE AND J. E. HURT, *Oklahoma State University.*—A number of samples cut from clear portions of Bolivian cassiterite crystals have been investigated for photoconductivity. The spectral response of the most sensitive sample showed a maximum at 3.44 ev corresponding with the short wavelength cutoff of the optical transmission and extended into the blue end of the visible spectrum. The full spectrum output of a mercury arc source was used to study the variation of photocurrent with time. Several crystals attained steady-state photocurrent values of the same order of magnitude as the dark current in times that ranged from seconds to hours depending upon the sample and its past history. Decays showed comparable variation. Currents in the maximum sensitivity specimen did not approach a steady-state value even after an increase of two orders of magnitude. Two very low resistance crystals showed no detectable photocurrent. Evidence was also obtained for fast response states. The light was chopped at 15 cps to determine the variation of photocurrent with light intensity. Over the intensity range of 40 to 400 microwatts/cm^2 a superlinear response was observed.

* Supported by the Office of Naval Research.

Y10. Radiation Powered Photon Amplification in Sulfide Phosphors. R. E. HALSTED, *General Electric Research Laboratory.*—It has been previously noted that radiation-powered photon amplification should exist in appropriate systems of three energy levels in solids. The behavior postulated for a system of three discrete levels[1] has an analog in a system comprised of a discrete level between valence and conduction

bands.[2] In a sample of hexagonal ZnS: 5×10^{-5} Cu, 5×10^{-5} Al powder[3] at 80°K, one 3.4-ev photon has been observed to control the production of more than 100 photons of 0.75-ev energy from a radiative power supply of 1.5-ev photons. A 3.4-ev photon is believed to excite an electron from a compensated Cu acceptor level to the conduction band. 1.5-ev photons then can excite electrons from the valence band to the empty Cu level. The recombination radiation associated with this transition occurs around 0.75 ev. If the recombination time associated with the excitation process at 3.4 ev is slower than that at 1.5 ev, the absorption and emission of many 1.5-ev and 0.75-ev photons, respectively, can be controlled by one 3.4-ev photon as observed. The origin of the recombination time difference has not been established.

[1] N. Bloembergen, Phys. Rev. Letters **2**, 84 (1959).
[2] Halsted, Apple, and Prener, Phys. Rev. Letters **2**, 420 (1959); **1**, 134 (1958).
[3] Samples provided by E. F. Apple and J. S. Prener.

SUPPLEMENTARY PROGRAMME

SP1. Hyperfine Structure of the $^3P_2$ State of Zn^{67}. A. LURIO, *I.B.M. Watson Laboratory.**—The hyperfine structure of $Zn^{67}(I=\frac{5}{2})$ in its metastable $^3P_2$ atomic state has been measured by the atomic beam magnetic resonance method. A beam of Zn atoms in the ground $^1S_0$ state is bombarded by electrons just after they emerge from the oven. This excites one in several thousand atoms to the $^3P_2$ state. The beam is detected on a potassium coated surface by electron ejection. The four hyperfine structure intervals were measured and are $\Delta\nu(\frac{9}{2},\frac{7}{2})=2418.111\pm0.025$ Mc/sec, $\Delta\nu(\frac{7}{2},\frac{5}{2})=1855.690\pm0.025$ Mc/sec, $\Delta\nu(\frac{5}{2},\frac{3}{2})=1312.064\pm0.025$ Mc/sec. $\Delta\nu(\frac{3}{2},\frac{1}{2})=781.865\pm0.025$ Mc/sec. From these measured intervals the dipole and quadrupole coupling constants are computed to be $a=531.987\pm0.025$ Mc/sec and $b=35.806\pm0.025$ Mc/sec. A check of the Breit-Wills theory will be discussed for two electron hyperfine structure from the above results for the $^3P_2$ state and the previously measured results in the $^3P_1$ state.[1] From the b coefficient, the quadrupole moment of the Zn^{67} nucleus is found to be $Q=0.17\times10^{-24}$ cm^2 in excellent agreement with previous results.[1]

* To be given at the end of Session P if the Chairman rules that time permits.
[1] Böckmann, Kruger, and Recknagle, Ann. Physik **20**, 250–257 (1957).

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Preliminary Announcement of the 1959 Winter Meeting in the West

The 1959 winter meeting of The American Physical Society in the West is to be held at the California Institute of Technology in Pasadena on Monday, Tuesday, and Wednesday, December 28, 29, and 30. The Department of Physics will be the host for the meeting, and most of the sessions will be held on the campus. There will be invited papers on low-energy nuclear physics, high-energy nuclear physics, low-temperature physics, theoretical physics, atmospheric physics, and cosmology.

The principal difficulty, as always at this time of the year, is the lack of hotel space in Pasadena. The local committee has been unable to get any sizable block of rooms set aside for the meeting in Pasadena. There is indication, however, that motels and some hotels will accept accommodations on an individual basis. A definite block of rooms has been set aside at the Statler Hotel in downtown Los Angeles, which will be held until ten days before the meeting. Members are urged strongly to plan their reservations as early as possible. Professor Ward Whaling of the Physics Department is Chairman of the local committee, and questions concerning physical arrangements should be addressed directly to him.

The deadline date for contributed papers is October 23.

Preliminary Announcement of the 1960 Annual Meeting

The 1960 Annual Meeting of the American Physical Society will be held in New York City, on Wednesday, Thursday, Friday, and Saturday, January 27, 28, 29, and 30. As usual, the American Association of Physics Teachers will hold concurrent sessions, and there will be a joint ceremonial session of the two societies comprising our Retiring Presidential Address, and the Richtmyer lecture and the Oersted prize presentation of AAPT. There will be a Business Meeting of our Society. Also as usual, the official hotel will be the New Yorker (New York 1, New York). It is not too early to make your reservations; in writing to the hotel, mention that you are coming to a meeting of this Society. The scientific sessions will be held in or near the New Yorker.

Deadline day is November 13, and abstracts are to be sent to Karl K. Darrow, Secretary, American Physical Society, Columbia University, New York 27, New York.

Preliminary Announcement of the 1960 Southwestern Meeting

In 1960 the Southwestern Meeting of the Society returns to its first home, the Rice Institute at Houston, Texas. The dates will be Friday and Saturday, March 4 and 5. Information as to hotels will be published in the Bulletin for the Annual Meeting.

Deadline day is Friday, January 8, and abstracts are to be sent to Karl K. Darrow, Secretary, American Physical Society, Columbia University, New York 27, New York. *Please be careful to mark your abstracts for the Southwestern Meeting, as deadline for the Detroit meeting arrives only a week later.*

Announcement of the 1959 Meeting of the Division of Fluid Dynamics

The Division of Fluid Dynamics of The American Physical Society will again hold its annual Divisional Meeting over the three days preceding Thanksgiving, namely, November 23, 24, and 25. The meeting will be on the campus of the University of Michigan, Ann Arbor, and will be devoted to various aspects of the physics of fluids, including superfluidity, hydrodynamics, magneto-fluid dynamics, rarefied gas dynamics, turbulence and boundary layer phenomena, and high-speed and high-temperature fluid flows. The scope of the Division of Fluid Dynamics covers kinetic theory, statistical mechanics, structure and dynamics of gases, liquids, and other fluids. Room reservations should be made individually by writing to the Michigan Union, Ann Arbor, Michigan, and mentioning the meeting of the Division of the Society.

1959 Conference on Magnetism and Magnetic Materials

Members of the Society who desire more information on this conference to be held in Detroit, November 16–20, 1959, should write to Dr. C. L. Hogan, Motorola Inc., 5005 McDowell Road, Phoenix, Arizona.

1960 Conference on Reactions between Complex Nuclei

A second conference on Reactions between Complex Nuclei will be held on May 2 and 3, 1960, at Gatlinburg, Tennessee. Any member of the Society who desires more detailed information should write to Dr. R. S. Livingston, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to Dr. Livingston (*not to the Secretary of the Society!*) and must reach him not later than April 2, 1960. Take note that it is the prerogative of the management of the Conference to accept or decline contributed papers that are offered.

Formation of a Division of Plasma Physics in The American Physical Society

The formation of the Division of Plasma Physics was approved by the Council of The American Physical Society on April 29, 1959. It is one of six Divisions within the Society devoted to the study of a specialized area of Physics.

Any Fellow or Member of The American Physical Society may enroll in the Division by paying an initiation fee of $2.00. There are no additional dues for the Division. An Organizing Committee of eight members, appointed by the President of the Society, has met and is at present preparing by-laws and formulating plans which will be submitted later to the membership of the Division.

The object of the Division shall be the advancement and diffusion of knowledge regarding the physics of highly ionized gases of natural or laboratory origin—including their creation, containment, heating, and acceleration; their radiations, oscillations, and stability; their transport, collective and wave properties, *et al.*

In addition to taking part in the regular meetings of the Society, the Division plans to organize Divisional meetings about once a year devoted exclusively to plasma physics. The first of these meetings will be held on December 3, 4, and possibly 5 at the Naval Postgraduate School in Monterey, California. Further information may be obtained from Dr. Frederic H. Coensgen, P.O. Box 808, Livermore, California.

Members of The American Physical Society who wish to enroll in this Division must fill out and mail the form hereunder, not forgetting the check for $2.00.

Melvin B. Gottlieb, *Chairman*
Marshall Rosenbluth, *Vice Chairman*
Alan C. Kolb, *Secretary-Treasurer*
Frederic H. Coensgen
Henry Hurwitz, Jr.
Wulf B. Kunkel
James A. Phillips
Albert Simon

Alan C. Kolb
Radiation Division Code 7412
Naval Research Laboratory
Washington 25, D. C.

Gentlemen:

I am a member of The American Physical Society. Please record me as a member of its Division of Plasma Physics. Herewith enclosed is my check (made out to American Institute of Physics) for two dollars as initiation fee.

Yours truly,

Name.....

Address.....

.....

MEETINGS AND DEADLINES THROUGH JUNE, 1960

Place	*Meeting dates*	*Deadline date*
Cleveland	November 27–28, 1959	past
Pasadena*	December 28–30, 1959	October 23
New York	January 27–30, 1960	November 13
Houston	March 4–5, 1960	January 8
Detroit	March 21–24, 1960	January 15
Washington	April 25–28, 1960	to be decided
Montreal	June 15–17, 1960	to be decided

* Abstracts for the Pasadena meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for topical conferences are to be sent to the addresses given on page 433.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

DIVISIONAL MEETINGS (see pages 433, 434)

Place	*Subject*	*Meeting dates*	*Deadline date*
Ann Arbor	Fluid Dynamics	November 23–25	past
Monterey	Plasma Physics	December 3–5	unknown

TOPICAL CONFERENCES (see page 433)

Detroit	Magnetism and Magnetic Materials	November 16–20	past
Gatlinburg	Reactions between Complex Nuclei	May 2–3, 1960	April 2

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original,* the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Program. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *If a member insists that his paper be scheduled for a particular day, this usually will entail that it be added to a session to which it is irrelevant.*

(*c*) *The Council has empowered the Secretary and his deputies to count a footnote either as ten words or as the actual length in words of the footnote, whichever is the greater figure.*

The American Physical Society

OFFICERS OF THE SOCIETY FOR 1959

President	G. E. UHLENBECK	University of Michigan
Vice-President	V. F. WEISSKOPF	Massachusetts Institute of Technology
Secretary	K. K. DARROW	Bell Telephone Laboratories (*retired*) (Office at Columbia University)
Treasurer	S. L. QUIMBY	Columbia University
Managing Editor	S. A. GOUDSMIT	Brookhaven National Laboratory

Past Presidents now on Council: W. F. G. Swann, E. P. Wigner, H. D. Smyth, and J. W. Beams.

Elected Members now on Council: S. K. Allison, N. F. Ramsey, Walker Bleakney, W. K. H. Panofsky, W. A. Fowler, Charles Kittel, Harvey Brooks, and Charles Hard Townes.

Local Secretary for the Pacific Coast	W. A. NIERENBERG	University of California, Berkeley
Deputy Secretary	W. W. HAVENS, JR.	Columbia University

Please cut along this line

(To be sent to Professor Leonard Olsen, Case Institute of Technology, Cleveland 6, Ohio.)

I expect to attend the banquet of Friday evening, November 27. My party will comprise ..... persons.

[If you want to be sure of having tickets, send with this form a check (made out to American Physical Society) for $4.00 multiplied by the number of banquet reservations. Your tickets will be held in your name at the desk.]

Name.....